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Module 4

Quantitative Analysis



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Chemistry 20

Module 4

Quantitative Analysis



Chemistry 20
Module 4: Quantitative Analysis
Student Module Booklet
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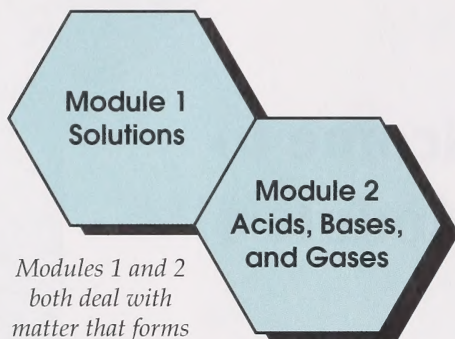
Welcome to Module 4!

We hope you'll enjoy your study
of *Quantitative Analysis*.

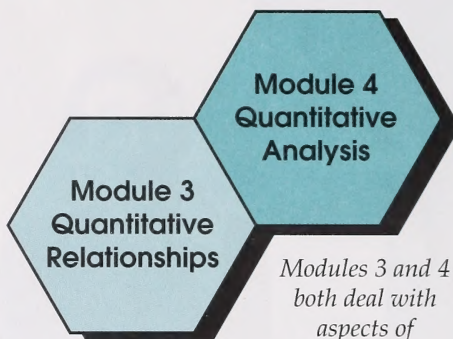
Remember, to make your
learning a bit easier, several
videocassettes and laser
videodiscs are referred to
throughout the modules. Your
textbook *Nelson Chemistry* will
also enhance your studies.

COURSE OVERVIEW

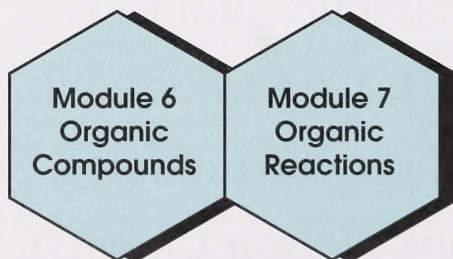
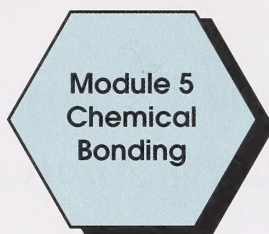
This course contains seven modules. The module you are working in is highlighted in deeper colour.



*Modules 1 and 2
both deal with
matter that forms
solutions.*



*Modules 3 and 4
both deal with
aspects of
stoichiometry.*



*Modules 6 and 7
both deal with
organic chemistry.*

MODULE

4

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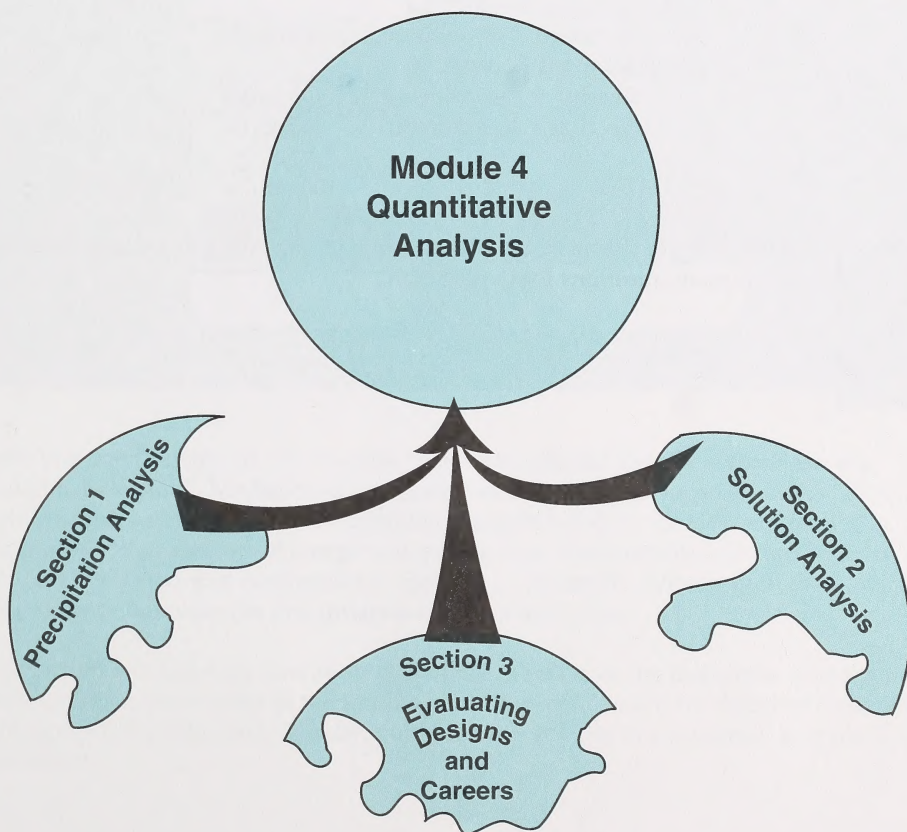
MODULE OVERVIEW

Have you ever found yourself asking questions like, how do they know how much fluoride to put in drinking water? Or, how do pharmaceutical companies know how much medication to put in cold tablets? The answers to these questions involve various forms of chemical analysis and research.

How do you think the Drug and Environmental Health Inspection Division performs quality control tests on different substances? The procedure involves quantitative chemical analyses to regulate concentrations of the chemicals in these substances.

In this module, you will work with several analysis techniques and learn how industry applies the knowledge of proportions to predict yields of commercial products.

A brief description of careers associated with the study of quantitative analysis will also give you an idea of the variety of job opportunities available.



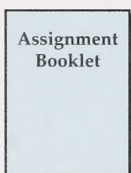
Evaluation

The document you are presently reading is called a Student Module booklet. It will show you, step by step, what to do and how to do it.

This module, Quantitative Analysis, has three sections. Within each section, your work is grouped into activities. Within the activities, there are readings and questions for you to answer. By completing these questions you will construct your own learning, discover scientific connections, and apply what you have learned. The suggested answers in the Appendix of this Student Module Booklet will provide you with immediate feedback on your progress.

In this module, you will be directed to the accompanying Assignment Booklets. You are expected to complete two Assignment Booklets for this module. Your grading in this module is based upon the assignments that you submit for evaluation. The mark distribution is as follows:

Assignment Booklet 4A	
Section 1 Assignment	40 marks
Assignment Booklet 4B	
Section 2 Assignment	40 marks
Section 3 Assignment	20 marks
TOTAL	100 marks

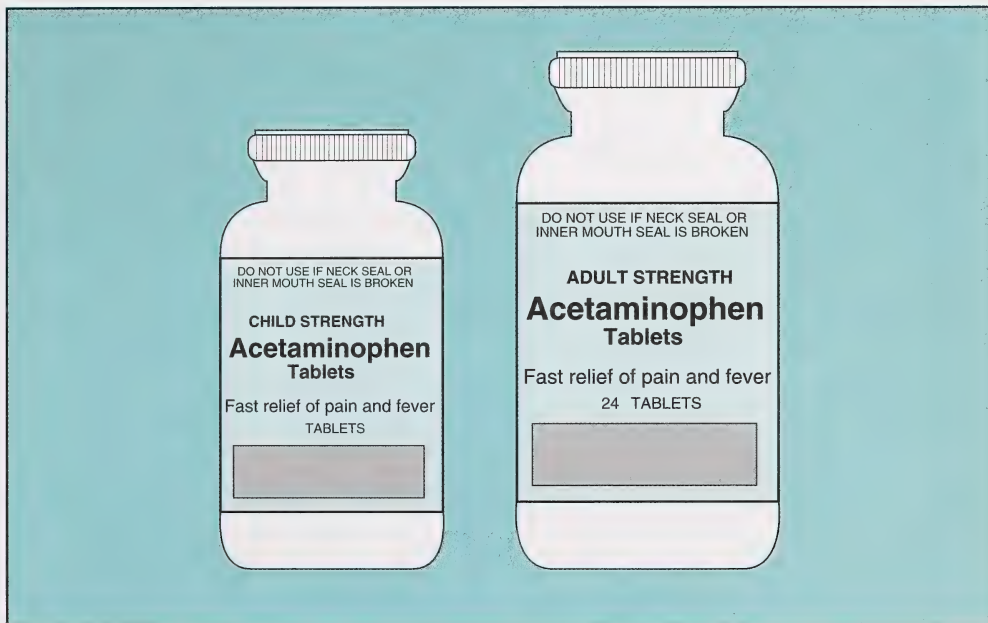


When you see this icon, turn to the appropriate Assignment Booklet to find the assignment questions for that section.

SECTION

1

Precipitation Analysis



Have you ever wondered what would happen if a doctor gave an adult dose of a medicine to a child? Medications are given based on body mass proportions. How do manufacturers arrive at the recommended dosages listed on the labels of medicine containers? Pharmaceutical companies and doctors use principles of stoichiometry to calculate the amount of medication in each dose. Research carried out in the medical laboratories often uses the precipitation analysis technique.

This section will focus on quantitative analysis which uses the principles of precipitation stoichiometry you learned in the last module. You will learn how chemical analyses using graphs is performed. Finally, you will explore how stoichiometry is applied to technology.

ACTIVITY

1 Quantitative Processes

What is it about orange juice that is good for you? Orange juice contains vitamin C. Do you know how much orange juice to drink in order to meet your daily vitamin C requirements?

quantitative analysis – the analysis of a sample to find the quantity of a specific substance present

Analytical chemists can use methods of **quantitative analysis** to find the precise vitamin C content in a given sample of orange juice. This analysis would allow dietitians in hospitals to control the vitamin C intake for their patients.

Orange Juice

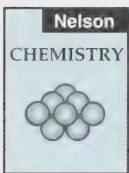


Daily Intake

1 glass?

2 glasses?

25 glasses?



To find out more about quantitative analysis, read Section 7.1 on page 165 in *Nelson Chemistry* and answer the following questions.

1. What is the difference between quantitative and qualitative chemical analysis?
2. State two important aspects of quantitative analysis.
3. What is a limiting reagent?
4. State the limiting reagent in the given recipe. Give a reason to support your choice.

Recipe

Fruit Punch

1 can apple juice
1 can ginger ale
1 can cranberry juice
2 cans orange juice

You have the following available:

				orange juice
		apple juice		
		cranberry juice		
	ginger ale			
↑ represents one can				

Check your answers by turning to the Appendix, Section 1: Activity 1.

precipitation reaction – a reaction in which an insoluble substance forms and separates from solution

precipitate – an insoluble substance formed as a result of a chemical reaction in solution

One type of quantitative chemical analysis technique uses a precipitation reaction as part of its design. This method uses the mass of a precipitate produced to find the mass of the reactant in an initial solution. You are familiar with this technique from the last module.

Lab Exercise 7A: Chemical Analysis Using a Graph

This lab exercise prepares you for an investigation dealing with precipitation analysis that you will do in Activity 2. Read Lab Exercise 7A on page 165 of *Nelson Chemistry* and do the following analysis.

5. The data given in the evidence table shows the combined mass of the precipitate and filter paper for solutions 1 and 2.
 - a. Calculate the mass of the precipitate only for each solution.

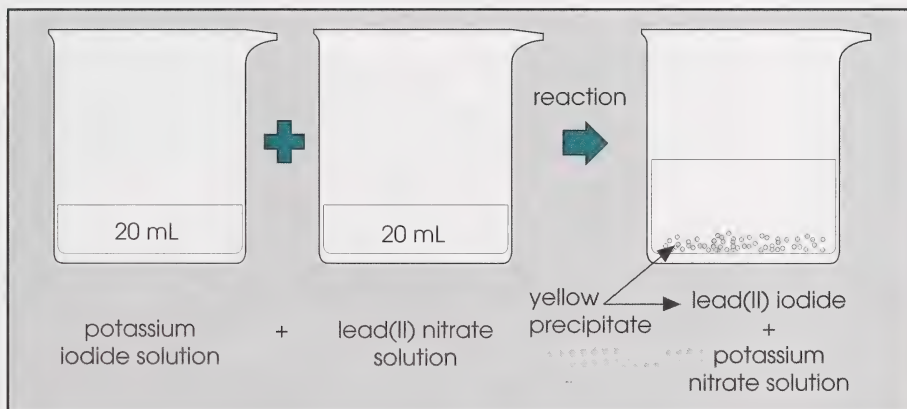
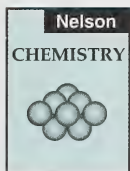
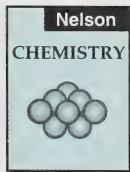


FIGURE 4.1: Precipitation of Lead(II) Iodide

- b. Write the balanced chemical equation for the precipitation reaction shown in Figure 4.1.
- c. Plot a graph of the Reference Data in Table 7.1 on page 165 of *Nelson Chemistry*. Be sure to use an appropriate scale on each axis. Title your graph **Relationship Between Mass of $\text{PbI}_{2(s)}$ and $\text{Pb}(\text{NO}_3)_{2(aq)}$** . Label the vertical axis **Mass of $\text{PbI}_{2(s)}$ (g)** and the horizontal axis **Mass of $\text{Pb}(\text{NO}_3)_{2(aq)}$ (g)**.

Note: You should use metric graph paper (10 mm) when constructing your graph. This will give you enough precision for the data points. You can buy this graph paper from most stationery shops or drugstores.



limiting reagent

– the reactant that is completely consumed when a reaction is taken to completion

excess reagent

– the reactant that is not completely consumed when a reaction is taken to completion

6. Use the information from the previous question to determine the original mass of lead(II) nitrate in each of the two solutions.

Check your answers by turning to the Appendix, Section 1: Activity 1.

As you learned earlier in this activity, precipitation reactions often involve a **limiting reagent** and an **excess reagent**.

7. Name the limiting reagent in Lab Exercise 7A and explain why you chose this substance.

The volume of the excess reagent added makes sure that all of the limiting reagent has reacted. Read the section Practical Considerations on page 166 of your textbook and use the information to answer the following question.

8. Explain how you could confirm that all of the limiting reagent has reacted.

Check your answers by turning to the Appendix, Section 1: Activity 1.

activated charcoal

– charcoal powder treated with chemicals to increase adsorption properties

adsorb – adhere or hold a thin layer of molecules (gases, liquids, or solutes) to the surface of a solid or liquid

The graph you prepared in Lab Exercise 7A is very similar to the type of graph that laboratory technicians and doctors have sometimes used in quantitative analysis. In present day situations, most of these analyses are performed using computer technology.

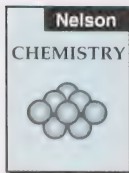
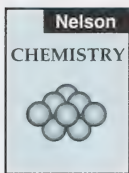
Stoichiometric principles can have wide applications. For example, they can be used to determine how much medicine to give a patient.

Activated charcoal is one of the important substances used in treating several types of poisonings. It is an insoluble powder and a wide variety of drugs and toxins can **adsorb** onto its surface. However, a knowledge of proportions is required to determine the amount of charcoal to be given, depending upon the amount of drug ingested. The ratio given is usually 10:1 (10 parts charcoal for every 1 part poison).



9. To review some of the ideas discussed, answer questions 1 to 3 from page 168 of your textbook.

Check your answers by turning to the Appendix, Section 1: Activity 1.



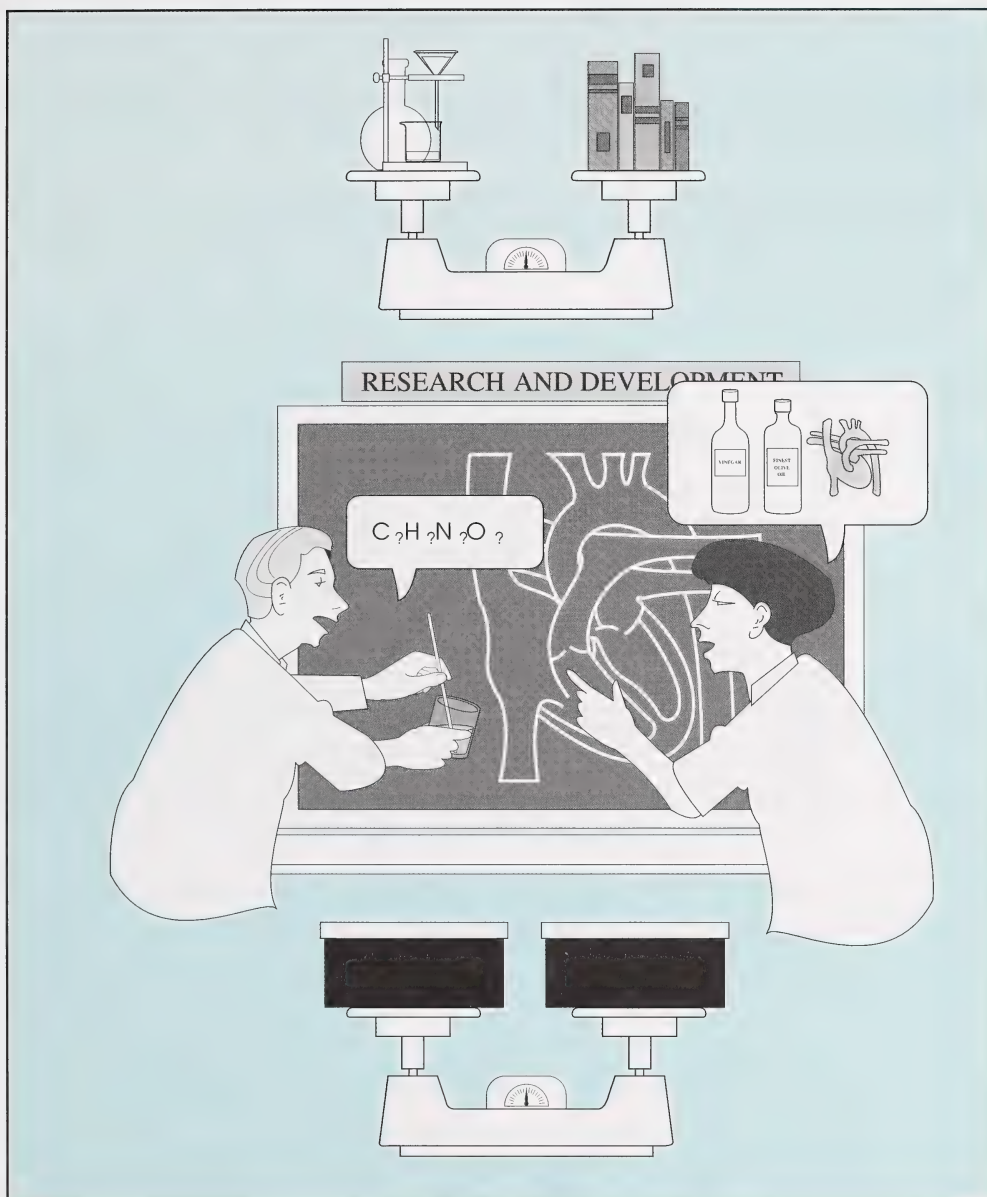


FIGURE 4.2: Quantitative Analysis and Technology

technology –
the application of
scientific
knowledge for
solving practical
problems

Can you think of any other areas that would use quantitative analysis?

The scientific principles you learn at school are also used in industry through **technology**. For example, the principles of stoichiometry, that substances react in definite proportions, form the basis of many commercial and technological processes.

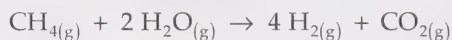
An example of an industrial technology which uses stoichiometric principles is the process of hydrogen production. Producing hydrogen is a large industry because it provides raw materials for industries such as petroleum refining, fertilizer production, and methanol production. The Shell Scotford Refinery near Fort Saskatchewan, Alberta, is involved in hydrogen production.

Scientific principles can be adapted to industry and they are critical for the efficient operation of a hydrogen plant. Engineers are constantly devising new techniques to increase the yield of the product.



"But we don't have the technology to do it."

In hydrogen plants, methane gas ($\text{CH}_{4(g)}$) is passed over steam ($\text{H}_2\text{O}_{(g)}$) in the presence of a catalyst to produce carbon dioxide ($\text{CO}_{2(g)}$) and hydrogen gas ($\text{H}_{2(g)}$).

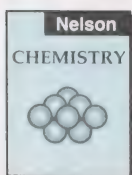


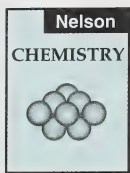
10. a. From the preceding equation, give the ratio in which methane and steam react.

(**Note:** Engineers usually use a 1:3 mole ratio of methane to steam. Can you tell why? Steam is used in excess to make sure that all of the methane reacts.)

- b. What is the limiting reagent in the preceding question?

To increase further understanding about science and its application to technology, read page 167 in *Nelson Chemistry*.





11. Do questions 7 and 8 (a-f) from page 168 of your textbook.

Check your answers by turning to the Appendix, Section 1: Activity 1.

You have seen how the principles of stoichiometry apply to quantitative analysis and how these basic principles can be applied to technology. Additional technologies will be examined in later activities.

ACTIVITY

2 Precipitation Reactions

Have you ever had a small puncture wound?

1. How long does a small puncture wound, such as a pin prick, normally take to stop bleeding?

Check your answers by turning to the Appendix, Section 1: Activity 2.

It doesn't usually take too long for your blood to clot and the bleeding to stop when you have had a minor injury.

Some people, however, suffer from a disease called haemophilia. The blood of haemophiliacs is extremely slow to clot or will not clot without the help of medication.

The quantity of medicine that a haemophiliac takes has to be carefully determined by a doctor. For example, if too much of the clotting medication is taken, the blood will start to coagulate while circulating in the body. How could the correct dosage be determined? The doctor could use a prepared reference graph that gives the relationship between body mass and the amount of the medication.

As you can see, simple precipitation relationships and quantitative predictions can have wide applications that extend beyond the chemistry lab.

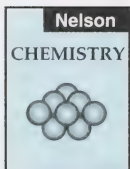
Another example where precipitation analysis may be useful is in the drying up of lakes due to extended periods of drought (as illustrated in the following photo). Concentrations of dissolved ions in the lake may become high enough to affect the fish and plant life. Biologists can use precipitation analysis as one method to assess the condition of the lake water.



AOSTRA

Now that you have examined the techniques involved in precipitation analysis, you are ready to perform an investigation of your own.

Investigation 7.1: Analysis of Sodium Carbonate Solution



Carefully read Investigation 7.1: Analysis of Sodium Carbonate Solution on page 166 of your textbook. Pay special attention to the required components, safety aspects, and applied science skills.

Guidelines

The following guidelines should be used for developing your investigation:

- Consider the points given under Practical Considerations on page 166 of *Nelson Chemistry* for help in developing your procedure.
- Refer to the filtration procedure on page 534 of your textbook for any necessary review.

2. List the materials required for this investigation.
3. List the steps to be followed in the procedure.

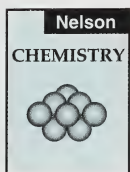
Check your answers by turning to the Appendix, Section 1: Activity 2.

Science Skills

- ☒ A. Initiating
- ☒ B. Collecting
- ☒ C. Organizing
- ☒ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

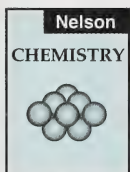
Before you continue, make sure your procedure is similar to the example given in the Appendix.

4. To complete the evidence for the investigation, prepare a data table and record your observations.
5. The following questions will complete the analysis for the investigation:
 - a. Use Table 7.2 on page 166 of *Nelson Chemistry* and plot a graph of the reference data. Be sure to use an appropriate scale on each axis. Title your graph **Mass of $\text{CaCO}_{3(s)}$ versus Mass of $\text{Na}_2\text{CO}_{3(aq)}$** . Label the vertical axis **Mass of $\text{CaCO}_{3(s)}$ (g)** and the horizontal axis **Mass of $\text{Na}_2\text{CO}_{3(aq)}$ (g)**.



Check your answers by turning to the Appendix, Section 1: Activity 2.

- b. Using your reference graph and the mass of the precipitate ($\text{CaCO}_{3(s)}$) produced, determine the mass of the sodium carbonate in the sample solution.
 - c. Using the mass of sodium carbonate you calculated in the previous question and the volume you used, calculate the concentration of sodium carbonate solution.
6. Write a dissociation equation for sodium carbonate. (Refer to Module 1 and page 129 of your textbook for a review of dissociation equations.)
7. Using the answers from the previous two questions, (the sodium carbonate concentration and the dissociation equation) determine the concentration of sodium ions and carbonate ions in the sodium carbonate solution.



Check your answers by turning to the Appendix, Section 1: Activity 2.

The following question will help to increase your understanding about the concepts developed in this investigation.

8.
 - a. Which reagent was in excess in this investigation?
 - b. How can you make sure that all of the limiting reagent has been used up?
9. Use your reference graph to complete the following chart:

Amount $\text{CaCO}_{3(s)}$ Produced	Mass $\text{Na}_2\text{CO}_{3(aq)}$ Reacted	Extrapolation or Interpolation
1.30 g		
2.80 g		

10. Use your reference graph to complete the following chart:

Amount $\text{Na}_2\text{CO}_{3(\text{aq})}$ Reacted	Mass $\text{CaCO}_{3(\text{s})}$ Produced	Extrapolation or Interpolation
2.75 g		
0.90 g		

Check your answers by turning to the Appendix, Section 1: Activity 2.

In the preceding investigation you had the opportunity to prepare a graph and use it to determine the proportions in which substances react by mass. The data that scientists collect can often be organized into reference tables or graphs. By using this data they can make quantitative predictions without having to repeat experiments.



However, society is developing technology such as the ion chromatograph and computer enhancement to replace hand-drawn reference graphs. In many instances lab technicians can obtain the desired information from the digital display of an instrument instead of having to interpret the required data from a reference graph.

In the next section you will look at another approach to quantitative analysis.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

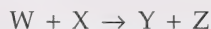
Review the main concepts covered in Section 1 by completing the following questions.

1. Use the following words to fill in the blanks.

- | | |
|------------------|-------------------------|
| • proportions | • stoichiometric |
| • precipitate | • precipitation |
| • graphs | • quantitative analysis |
| • reference data | • solute |

- a. Some of the most important measurements in chemistry are _____ measurements.
 - b. These measurements are important because they show the _____ in which various substances react.
 - c. In this section you used the stoichiometry of _____ reactions for _____. This method requires mixing solutions of ionic compounds. The new combination of ions may produce a substance which may not dissolve appreciably in water, and therefore settles as a solid. This solid is called a _____.
 - d. _____ prepared in advance from _____ can be used to predict the mass of a substance in a sample of a solution. They can show the relationship between different masses of the low solubility substance and the _____ in the original sample solution.
2. Identify each of the following statements as true or false.
- a. If equal volumes of reagents are mixed it is unnecessary to check that a sample has completely reacted.
 - b. A few drops of limiting reagent are added to the precipitate mixture to check if a sample has completely reacted.
 - c. When verifying the complete reaction of a limiting reagent, a few drops of the excess reagent are added. If cloudiness does not appear, the procedure should not be repeated.

3. a. Use Figure 4.3 to construct a reference graph for the reaction of substance X with excess substance W, represented by the following chemical equation:



Trial	Mass of Z Produced (g)	Mass of X Reacted (g)
1	0.50	1.00
2	1.00	1.50
3	1.50	2.00
4	2.00	2.50
5	2.50	3.00

FIGURE 4.3: Reference Data

Title your graph **Relationship Between Mass of X and Z**. Label the vertical axis **Mass of Z (g)** and the horizontal axis **Mass of X (g)**.

- b. Complete the following chart, using your graph as a reference.

Mass of Z Produced (g)	Mass of X Reacted (g)
	1.25
0.80	
	1.70
1.95	
	3.40

- c. Which substance is the limiting reagent in each of the trials?
- d. Which substance provides the responding variable data?

Check your answers by turning to the Appendix, Section 1: Extra Help.

Enrichment

Do any **one** of the following questions.

- Evaluate the usefulness of the technique which uses principles of precipitation stoichiometry for determining the concentration of a solution in an industry-related laboratory. Refer to the Appendix, Section 1, Enrichment, question 1, for some suggestions.
- Visit a local medical laboratory and investigate how the medical laboratories use precipitation stoichiometric principles in the Benedict's test for diabetic patients.

3. Write a brief report on how water becomes "hard", and explain one method that uses precipitation techniques to make water "soft".

Check your answers by turning to the Appendix, Section 1: Enrichment.

Conclusion

In chemistry you learn how and why substances react the way they do. Scientific principles are used by researchers, technicians, engineers, doctors, and nurses in their professions for industrial or everyday activities. Quantitative analysis is one of the tools which technology uses for research and commercial application.

Assignment
Booklet

ASSIGNMENT

Turn to Assignment Booklet 4A and do the assignment for Section 1.

Solution Analysis



WESTFILE INC.

Have you ever looked at the labels of soft drinks or cleaning products? Most of the drinks and some of the cleaning products contain acids. Do you know how much acid is present in a can or bottle of pop for example? What units are used to express the acid concentration? Solution analysis techniques can be used to find the concentration of the acid in these beverages or cleaning products.

In this section you will review the different units in which concentration can be expressed and the volumetric techniques used to find the concentration of a solution.

ACTIVITY

1 Communicating Concentration of Solutions

What is it about orange juice that is good for you? Orange juice contains vitamin C. Do you know how much orange juice to drink in order to meet your daily vitamin C requirements?

Analytical chemists can use methods of quantitative analysis to find the precise vitamin C content in a given sample of orange juice. This analysis would allow dietitians in hospitals to control the vitamin C intake for their patients.

The following is a sample test report of a patient in a hospital.

Test/Comment	Results	AB	Low	Normal	High	Units	- Normals -	Tech
M12								
Calcium	2.04	L	*			mmol/L	2.17-2.55	EM
Phosphorus	0.76	L	*			mmol/L	0.80-1.50	EM
Uric acid	307			*		umol/L	225-420	EM
Lactic dehydrogenase	136			*		U/L	100-190	EM
Creatine kinase	40			*		U/L	20-235	EM
Total bilirubin	15			*		umol/L	0-16	EM
Alkaline phosphatase	55			*		U/L	50-136	EM
Gamma GT	28			*		U/L	15-85	EM
Protein, total	60			*		g/L	60-82	EM
Albumin	35			*		g/L	35-50	EM
Direct bilirubin	4			*		umol/L	0-6.0	EM
Alt	16			*		U/L	3-36	EM

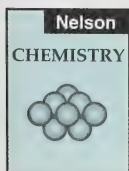
What units are used to communicate concentrations of substances listed in medical test reports, food labels, or environmental reports? This activity looks at the different possibilities.

1. From your previous studies, what does the term *concentration* mean?

Check your answers by turning to the Appendix, Section 2: Activity 1.

In Module 1 you calculated concentration in terms of moles per litre (mol/L), but in industry and everyday household products, amounts of substances can be expressed in a number of different ways. Whatever method you use to calculate concentration, it is still a ratio of quantity of solute to quantity of solution. The only difference is that the units used to express it are different.

Read the section Communicating Concentration Ratios in the middle of page 124 of your textbook, to find some common ways to express concentration.

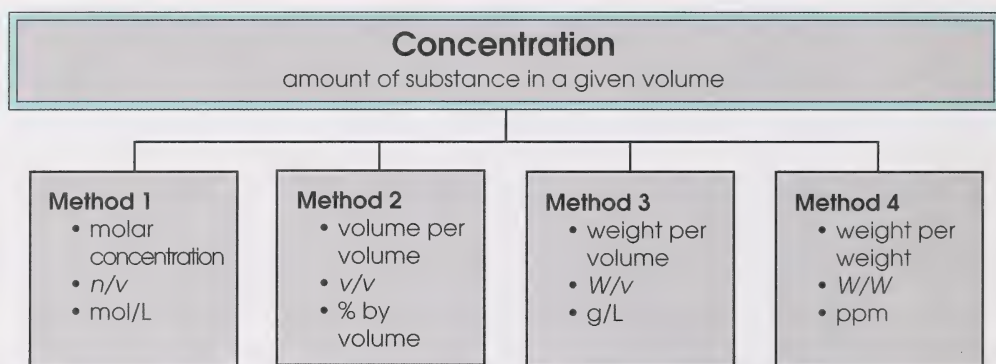


2. List four different units that are used to communicate concentration.

Check your answers by turning to the Appendix, Section 2: Activity 1.

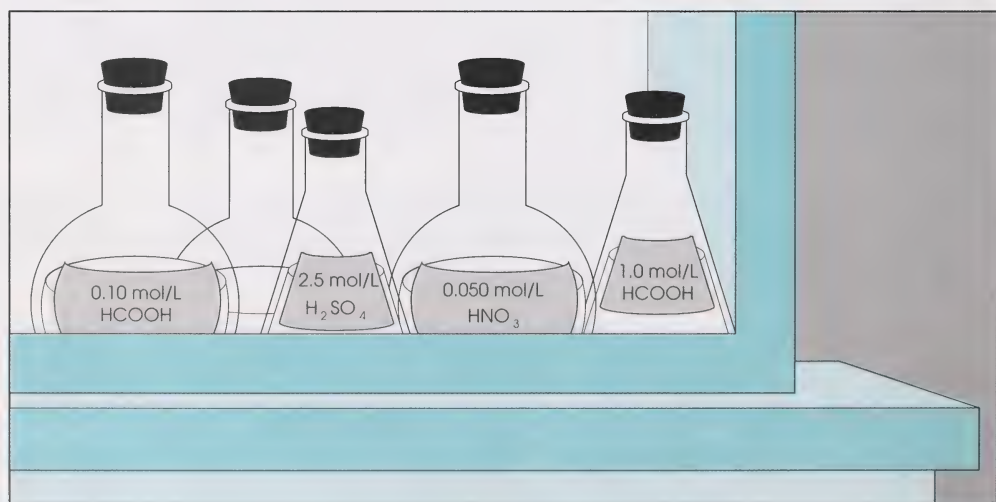
How do you calculate concentration using these variables?

The following chart gives a brief overview of four different methods used to express concentration.



Note that the older term *weight* and the symbol W are used, even though mass is actually measured in grams.

Method 1: molar concentration (n/v)



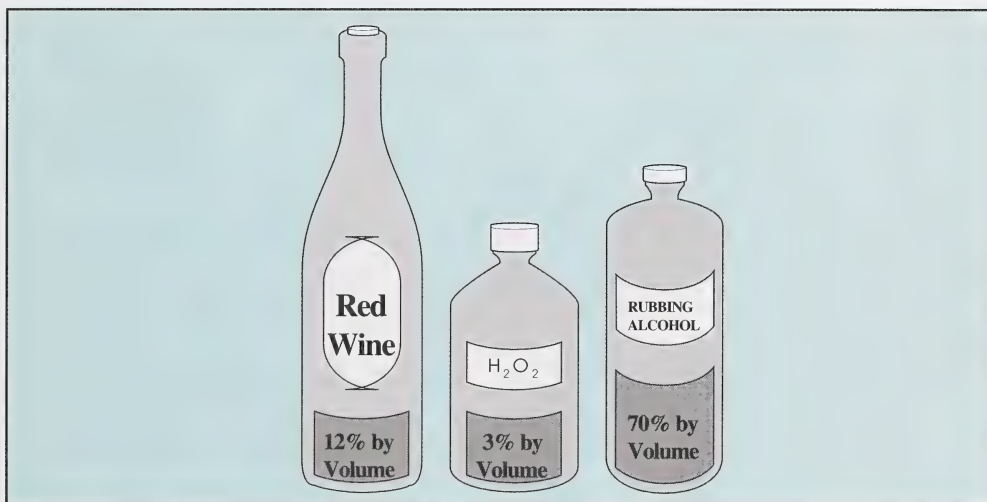
In Module 1 you performed calculations to find the concentration of various solutions.

3. What relationship is used to calculate molar concentration?

Check your answers by turning to the Appendix, Section 2: Activity 1.

The unit for molar concentration is frequently used in chemical laboratories but is not used frequently in commercial products. To review molar concentration, refer to Module 1.

Method 2: volume/volume (v/v)



When are percent units used to express concentration? When the solute and the solvent are both liquids, their ratio is expressed by using percent by volume.

A wine labelled 12% alcohol means there are 12 mL of alcohol per 100 mL of wine.

$$\text{Concentration} = \frac{\text{Volume of solute}}{\text{Volume of solution}}$$

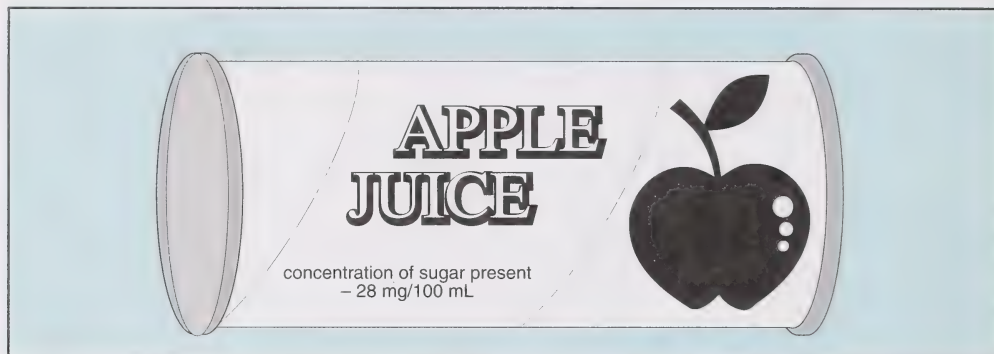
To change this value to percent, the ratio in the given relationship is multiplied by 100.

$$\begin{aligned} \text{Concentration of alcohol in wine} &= \frac{12 \text{ mL alcohol}}{100 \text{ mL wine}} \times 100 \\ &= 12\% \end{aligned}$$

4. A volume of 20 mL of acetone (nail polish remover) is diluted with water to make 100 mL of solution. What is the final concentration of the solution in percent by volume? Show your calculations.

Check your answers by turning to the Appendix, Section 2: Activity 1.

Method 3: weight/volume (W/v)



5. The concentration of sugar or artificial sweeteners in beverages is often expressed using weight to volume ratios.
- Write a mathematical equation to express this relationship.
 - What are the units for expressing concentration using this relationship?

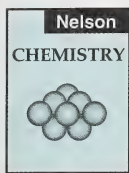
Check your answers by turning to the Appendix, Section 2: Activity 1.

Read the following example for better understanding.

Question: Mischa's blood glucose concentration is 0.080% W/v. What does this statement mean?

Answer: It means that there are 0.080 g of sugar per 100 mL of Mischa's blood.





You will find other examples of expressing concentration on pages 124 (starting with Concentration-Quantity Calculations) and 125 in *Nelson Chemistry*. Study the examples carefully.

6. Do questions 12, 13, 14, and 15 from pages 125 and 127 in your textbook.
7. One type of rubbing alcohol that can be purchased from drugstores or pharmacies is a 93% *W/v* solution of ethanol. What mass of ethanol ($\text{C}_2\text{H}_5\text{OH}$) would be in 25 mL of the rubbing alcohol solution?

Check your answers by turning to the Appendix, Section 2: Activity 1.

Method 4: weight/weight (W/W)

How is a concentration of DDT in the environment expressed? Often in environmental studies, the unit *ppm* is used to express concentration. The abbreviation *ppm* represents *parts per million*. Why do you think engineers decided on this unit? When chemical concentrations are very small, as is often the case with toxic chemicals, ppm is the preferred concentration unit.

Calculations involving this method use the following relationship:

$$\begin{aligned} \text{concentration} &= \frac{\text{weight of substance}}{\text{weight of solution}} \\ \text{or actually} &= \frac{\text{mass of substance}}{\text{mass of solution}} \end{aligned}$$



WESTFILE INC.

Read the following example for better understanding.

Guideline: PCB contaminations of greater than 50 ppm are injurious to health.

Question: The Bow River in Kananaskis country has 0.0060% PCBs. Is this water hazardous to wildlife living in the area?

Answer: The concentration in ppm of PCBs may be calculated as follows:

$$\begin{aligned}\text{concentration} &= \frac{\text{mass of substance}}{\text{mass of solution}} \\ 0.0060\% \text{ means } \frac{0.0060 \text{ g}}{100 \text{ g}} &= \frac{0.000060 \text{ g PCB}}{1 \text{ g solution}} \\ &= \frac{60 \text{ g}}{1\,000\,000 \text{ g}} \\ &= 60 \text{ ppm}\end{aligned}$$

Conclusion: A concentration of 0.0060% PCBs or 60 ppm is hazardous to wildlife.

8. A bottle of spring water has a label indicating a concentration of Mg as 24 ppm. What mass of magnesium is present in a 500 mL bottle of spring water? (Remember, water has a density of 1 g/mL at room temperature.)

Check your answers by turning to the Appendix, Section 2: Activity 1.

The low concentrations you have been working with are often the result of substances being diluted as they diffuse into the environment. Smokestack emissions containing gases such as CO_2 , SO_2 , and CO , get diluted as soon as they are released into the atmosphere.

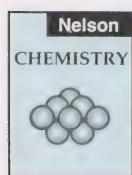
The various units used to express concentration can be used in **dilution** problems as well. Carefully study the examples on pages 127 and 128 of your textbook and complete the following questions which deal with dilution situations.

9. Do questions 16, 17, 18, and 19 from page 128 of your textbook.

Check your answers by turning to the Appendix, Section 2: Activity 1.

You have discovered that the varied needs of industry and society require the expression of concentration in different units. The common factor in all the units was the ratio of quantity of solute to the quantity of solution. In the next activity you will learn about a technique used to determine concentration of solutions.

dilution –
decreasing the
concentration of
a solution by
increasing the
amount of
solvent



ACTIVITY

2 How Concentrated Is It?

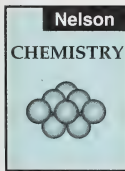
titration – the process of progressively adding a precise volume of one solution from a buret to a known volume of another solution in a flask



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Are you one of the many people who are sensitive to the acid contained in citrus fruits or soft drinks? If you wanted to know if a new kind of soft drink has too much acid for you, how could you go about finding out?

One procedure you could use is a method of quantitative analysis called **titration**. By using titration analysis, you can determine the concentration of a substance in a solution. This method is especially useful in the analysis of the concentrations of acidic and basic solutions, as you studied in Module 2.



Before you can learn about the titration technique, you need to know the terminology related to solution analysis. Read page 190 and the top of page 191 in your textbook, paying special attention to Figure 7.21, and answer the following questions to review terms and equipment.

1. Indicate whether each of the following statements regarding titration is true or false.
 - a. The solution in the Erlenmeyer flask is called the titrant.
 - b. Titration is the progressive addition of a titrant into a measured volume of a sample.
 - c. A sudden change in the property of a solution in the Erlenmeyer flask represents the equivalence point.
 - d. A solution of known concentration is called a standard solution.
 - e. The **endpoint** indicates the volume of the titrant at the endpoint.

endpoint – the point at which there is a sudden change in the property of the solution when a reaction is complete

Titration techniques are used widely in research and industry. Titration analysis requires a special apparatus and technique. A typical titration setup is shown in Figure 4.4.

- Identify each of the labelled equipment parts in the given diagram, Figure 4.4, Titration Setup.
- What other materials, other than those shown in Figure 4.4, are needed for a titration? (**Hint:** You can refer to Figure 7.21 on page 191 of your textbook for assistance.)

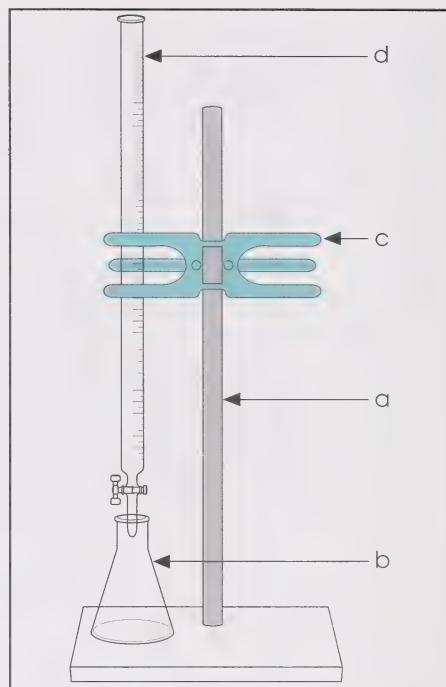
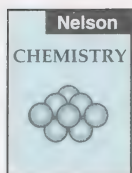


FIGURE 4.4: Titration Setup

Check your answers by turning to the Appendix, Section 2: Activity 2.

titrant – the solution added from the buret during a titration procedure

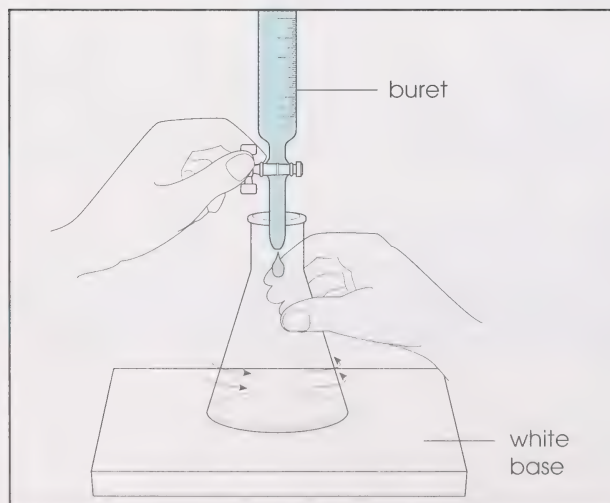
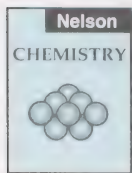
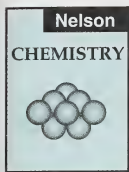


FIGURE 4.5: Typical Titration Technique

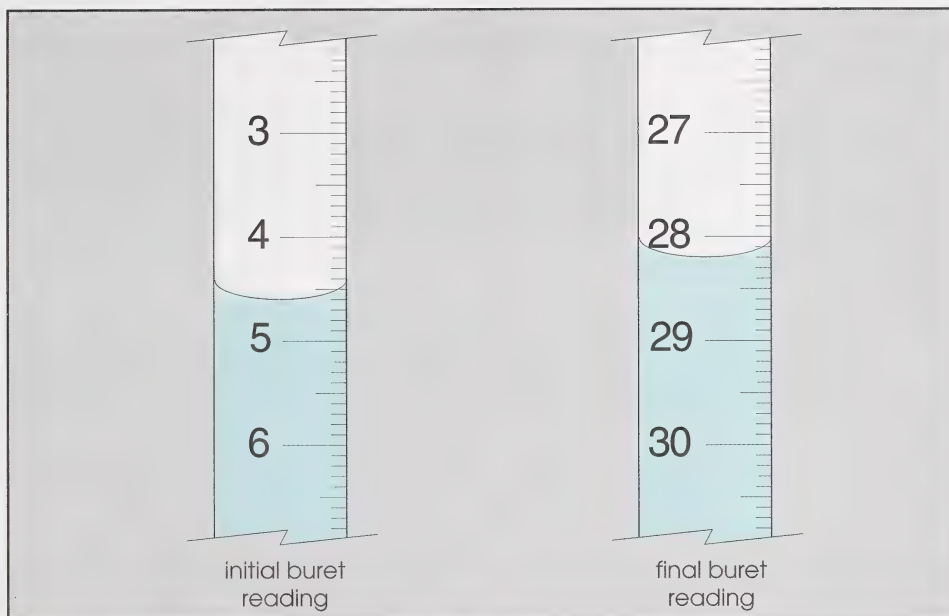
The titration procedure requires the progressive addition of the **titrant** to a sample in the flask.

Figure 4.5 shows a typical titration technique. The technique is also illustrated in Figure 7.21 on page 191 and described on pages 536 and 537 of your textbook.



Read the information given beside Figure 7.21 on page 191 of your textbook, and answer the following question to check your understanding of using a buret.

4. You are given the following burets:



What is the net volume of the solution used?

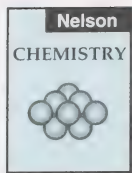
5. a. Complete the following table:

Titration of 10.00 mL of $\text{HCl}_{(\text{aq})}$ with 0.10 mol/L $\text{KOH}_{(\text{aq})}$			
Trial	1	2	3
Final buret reading (mL)	10.8	15.2	13.6
Initial buret reading (mL)	0.50	5.0	3.2
Volume of $\text{KOH}_{(\text{aq})}$ used (mL)			

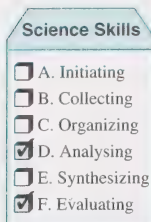
- b. From the preceding table calculate the average volume of potassium hydroxide used.

Check your answers by turning to the Appendix, Section 2: Activity 2.

Lab Exercise 7H: Titration Analysis of Vinegar



To prepare you for doing your own titration in the upcoming investigation, do Lab Exercise 7H on page 191 of your textbook. The following questions make up the analysis for the lab exercise.



6. Use the titration evidence given to determine which trial is probably flawed due to error in technique.
7. Using the unflawed readings, calculate the average volume of sodium hydroxide solution used.
8. Write the equation for the reaction between vinegar (acetic acid) and sodium hydroxide.

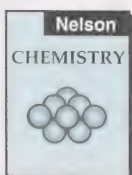
Check your answers by turning to the Appendix, Section 2: Activity 2.

9. a. Using the average volume of sodium hydroxide that you calculated and the given concentration of sodium hydroxide, calculate the moles of sodium hydroxide reacted.
- b. Using the mole ratio of sodium hydroxide to vinegar and the moles of sodium hydroxide reacted, calculate the moles of vinegar reacted.
- c. Calculate the concentration of vinegar using your preceding answer and the volume of vinegar used.

Check your answers by turning to the Appendix, Section 2: Activity 2.

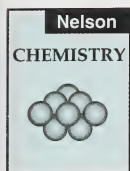
As you discovered in Module 3, the solutions to the preceding question (a, b, and c) can be combined and written in one line as follows:

$$C_{(\text{CH}_3\text{COOH})} = 13.0 \text{ mL} \times \frac{0.202 \text{ mol NaOH}}{\text{L}} \times \frac{1 \text{ mol CH}_3\text{COOH}}{1 \text{ mol NaOH}} \times \frac{1}{10.00 \text{ mL}}$$



Both calculation methods give the same final answer.

Now that you are familiar with the factors involved in titration analysis, read the section Using a Pipet in Appendix C on pages 532 and 533 in your textbook. You will need pipetting skills for the next investigation. It is recommended that you initially practise your pipetting technique with water to improve your skills.



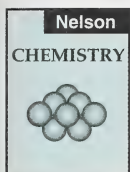
You should also review Investigation 7.5 dealing with standard solutions on page 186 of your textbook before doing Investigation 7.7.

Investigation 7.7: Titration Analysis of Hydrochloric Acid

PATHWAYS

If you have access to laboratory facilities, do Part A.
If you do not have access to laboratory facilities, do Part B.

Part A



Carefully follow the directions given for Investigation 7.7 on page 192 of *Nelson Chemistry*. Pay special attention to the required components, safety aspects, and applied science skills. As part of the prelab preparation, complete the following two questions.

10. a. Do step 1 of the procedure on page 192 of your textbook.
- b. Write the balanced chemical equation for the reaction between $\text{HCl}_{(\text{aq})}$ and $\text{Na}_2\text{CO}_{3(\text{aq})}$.
11. Prepare a data table similar to the one in Lab Exercise 7H (page 191 of your textbook) for recording your evidence.

Science Skills

- ☒ A. Initiating
- ☒ B. Collecting
- ☒ C. Organizing
- ☒ D. Analysing
- ☐ E. Synthesizing
- ☒ F. Evaluating

Check your answers by turning to the Appendix, Section 2: Activity 2.

Set up the apparatus for the titration as shown on page 191 of your textbook and complete steps 2 to 9 of the procedure.

If you prefer, the next question (parts a, b, and c) can be set up in one line as described earlier.

12. a. Calculate the moles of sodium carbonate that reacted from the mass of $\text{Na}_2\text{CO}_{3(\text{aq})}$ you calculated for Step 1 and the information given in Step 5 of the procedure.
- b. Calculate the moles of hydrochloric acid that reacted by using your calculated moles of sodium carbonate that reacted and the mole ratio of hydrochloric acid to sodium hydroxide from the balanced equation.

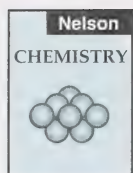
- c. Calculate the concentration of the hydrochloric acid by using your calculated moles of hydrochloric acid that reacted and the average volume of the acid sample you used.

The calculation performed in the preceding question answers the problem stated in the investigation.

Check your answers by turning to the Appendix, Section 2: Activity 2.

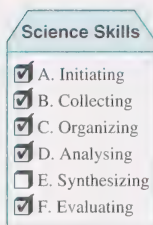
End of Part A

Part B



Carefully read the directions given for Investigation 7.7 on page 192 of *Nelson Chemistry*. Pay special attention to the required components, safety aspects, and applied science skills.

If you do not have access to a buret, use a 10 mL pipet. Follow the procedure given here for the investigation.



Procedure

- Place 70-80 mL of $\text{HCl}_{(\text{aq})}$ in a clean, dry beaker or glass.
- Pipet a 10.00 mL sample of $\text{Na}_2\text{CO}_{3(\text{aq})}$ into a clean, dry beaker or glass and add 1 to 3 drops of methyl orange indicator.
- Rinse out the pipet with a small portion of $\text{HCl}_{(\text{aq})}$.
- Using the pipet, carefully add $\text{HCl}_{(\text{aq})}$ solution to the $\text{Na}_2\text{CO}_{3(\text{aq})}$ until a single drop produces a permanent colour change from pale yellow to pink.
- Be sure to record your initial volume of $\text{HCl}_{(\text{aq})}$ on the pipet, and the final volume so you can calculate the net volume of $\text{HCl}_{(\text{aq})}$ used.
- Repeat the first three steps until three consistent results are obtained.

Complete the following questions.

13. a. Do step 1 of the procedure on page 192 of your textbook.
- b. Write the balanced chemical equation for the reaction between $\text{HCl}_{(\text{aq})}$ and $\text{Na}_2\text{CO}_{3(\text{aq})}$.

14. Prepare a data table similar to the one in Lab Exercise 7H (page 191 of your textbook) for recording your observations as evidence.
15. The following calculations may be arranged on one line, if so desired. The calculations answer the problem stated in the investigation.
 - a. Calculate the moles of sodium carbonate that reacted.
 - b. Using your calculated moles of sodium carbonate that reacted and the mole ratio of hydrochloric acid to sodium hydroxide from the balanced equation, calculate the moles of hydrochloric acid that reacted.
 - c. Using your calculated moles of hydrochloric acid that reacted and the average volume of the acid sample you used, calculate the concentration of the hydrochloric acid.

Check your answers by turning to the Appendix, Section 2: Activity 2.

End of Part B

The titration techniques you have learned are sometimes used in research dealing with human physiology. You have probably heard about a condition called an ulcer. An ulcer is usually associated with an excess of one of the stomach secretions (gastric secretion) – $\text{HCl}_{(\text{aq})}$. Research scientists sometimes perform **intra**gastric titrations for diagnostic purposes.

intragastric –
inside the
stomach

The technique requires no anaesthetization or surgery. A tube inserted through the mouth into the stomach either collects gastric juice for analysis or infuses known quantities of base to neutralize the acid. The concentration of the stomach acid can then be calculated.



This is one example of the application of titration analysis in technology, but titration analysis has a wide range of use in industry as well.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

Review the main concepts covered in this section by doing the following questions.

1. Match the unit to the statement that describes its concentration.

Statement	Unit
a. moles of solute in a litre of solution	i. ppm
b. mass of solute in the solution	ii. percent by volume
c. volume of the solute in the solution	iii. $\frac{\text{mol}}{\text{L}}$
d. parts of the solute to parts of solution	iv. g/L

2. Use the following words to fill in the blanks.

- | | | |
|------------|---------------------|-------------|
| • endpoint | • indicator | • titration |
| • titrant | • standard solution | |

- a. _____ is an analytical procedure used to determine the concentration of a solution using a standard solution.
 - b. A solution of known concentration is called the _____.
 - c. The _____ is the solution in the buret.
 - d. The sudden change in a property of a solution indicating completion of a reaction is called the _____.
 - e. An _____ is a chemical added to a solution being titrated to signal the endpoint.
3. a. List the equipment you would need to do the titration of an oxalic acid solution with 0.10 mol/L sodium hydroxide solution.
- b. Identify the titrant in this investigation.
- c. Identify the standard solution in this investigation.

Check your answers by turning to the Appendix, Section 2: Extra Help.

Enrichment

Do any **one** of the following choices.

Science Skills

- ☐ A. Initiating
- ☒ B. Collecting
- ☒ C. Organizing
- ☒ D. Analysing
- ☐ E. Synthesizing
- ☒ F. Evaluating

1. Antacid tablets contain basic substances that react with and neutralize acid ($\text{HCl}_{(\text{aq})}$) in the stomach. Perform an investigation to determine the amount of acid that some commonly used antacids can neutralize. Compare the antacids in terms of their relative strengths.
2. Investigate how titration procedures have been modified by recent advances in technology for use in industrial laboratories.
3. Fruits such as lemons, oranges, limes, and grapefruit are acidic. Their acidity is mostly due to citric acid. It is for this reason that they are called citrus fruits. Citrus acid has the molecular formula $\text{C}_6\text{O}_7\text{H}_8$.

Using ammonia as a base, present in common household cleaners, outline an investigation for finding which juice has the highest acidity.

Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

In this section you have discovered that the concentration of a substance can be expressed in several different units. It is often necessary to determine the concentration of substances in a solution. Titration analysis is an important technique that helps you determine concentration efficiently and simply.

ASSIGNMENT

Turn to Assignment Booklet 4B and do the assignment for Section 2.

Assignment
Booklet

Evaluating Designs & Careers



You often hear claims on television that one type of suntan lotion is better than another. Promoters talk about the importance of sun protection factors, the need for skin conditioners, and how their product does a better job. How would you verify their claim? To test the validity of their claim you would need to develop an experimental design that would test the difference between the many products.

This section looks at the criteria used to design an experiment and how to apply these criteria when selecting the most appropriate design from several alternatives available.

Through television, you have also been exposed to the enormous amount of technology in the world today and many different careers that make use of these technologies. This section will also examine several careers involving science and technology and will emphasize the need for a good science education in high school.

ACTIVITY

1 Developing Experimental Designs

What is the concentration of vinegar in coffeepot cleaner?

Methods

filtration

titration

crystallization

gas collection

Which procedure should I choose?

1. Which procedure would you choose to answer the problem stated in the preceding illustration?

You have discovered several designs and procedures in your studies so far that could be used to answer several different problems. Designs developed to solve chemical analysis problems incorporate one or a combination of procedures used in lab processes. Gas collection was discussed in Module 3. Titration analysis was discussed in Section 2 of this module. Other designs include **crystallization** and filtration.

crystallization – a technique involving crystal formation by vaporizing the solvent

salt – an ionic compound, usually white, which contains neither H^+ or OH^- ions

Following is a brief review of the processes of crystallization and filtration.

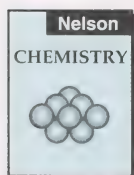
Crystallization

How do you think the world's **salt** deposits were formed? Salt deposits can be found in the deepest caves, on the highest plateaus, or in your kettle at home. Salts dissolve easily in water, therefore water bodies such as the ocean and a few lakes have a high concentration of salt. However, water evaporates at a very high rate. The level of many lakes can decrease 2.5 cm/day in warm weather. When lakes, rivers, and oceans dry up, salt deposits are left behind.

A crystallization process could be used to determine the concentration of salt in sea water. Salt deposits are also left behind in many eerie forms as a result of groundwater containing dissolved salts dripping in underground caves. The concentration of groundwater salts could also be found by the process of crystallization.



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Read the section Crystallization on pages 533 and 534 in your textbook and answer the following questions.

2. The following steps for determining the concentration of salt in sea water or groundwater using a crystallization procedure are out of order. Place the steps in correct sequence by labelling them a, b, c, etc.
 - _____ Heat the solid with a hot plate to drive off any remaining solvent, allow it to cool, and measure the mass of the solid.
 - _____ Record the mass of a clean, heat-resistant evaporating dish.
 - _____ Measure and record the mass of the dish and solid when dry.
 - _____ Pour a measured volume of solution in the evaporating dish.
 - _____ Evaporate the solution slowly either using a gentle heat source or letting it stand until all solvent evaporates.

3. In which two ways is the temperature variable manipulated in this crystallization process? Explain why.

Check your answers by turning to the Appendix, Section 3: Activity 1.

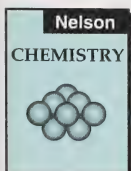
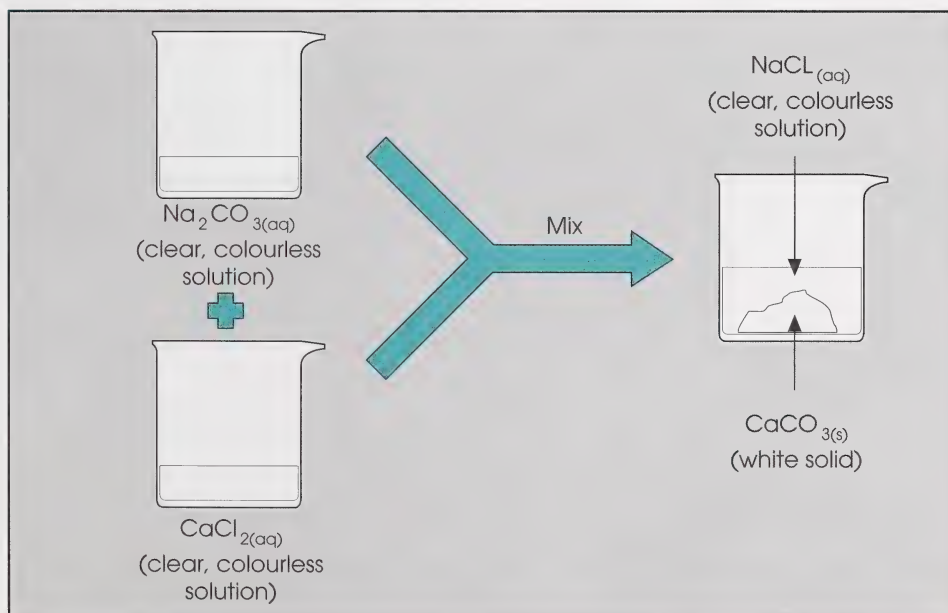
You will find that the crystallization process is not usually suitable for isolating substances that have low boiling points. An alternate method for these substances could be **fractional distillation**.

fractional distillation – a method of separating the components of a mixture based on the components' different boiling points

What is the difference between crystallization and filtration?

Filtration

Often different ionic solutions can be mixed to form a precipitate. You precipitated calcium carbonate from a reaction between sodium carbonate and calcium chloride during Investigation 7.1.



The experimental design required a filtration procedure to measure the mass of the precipitate.

Read the section on filtration on pages 534 to 535 of *Nelson Chemistry* to review the steps in this process and then answer the following two questions.

4. Draw a diagram showing the equipment you would use to perform a filtration procedure and label the apparatus.
5. List three factors that are important for obtaining accurate results in a filtration process.

Check your answers by turning to the Appendix, Section 3: Activity 1.

It is not only important for you to understand how to carry out various procedures such as the ones discussed in this activity. Another important skill is the evaluation of the experimental designs.

ACTIVITY

2

Experimental Designs



Problem: Which of the lotions illustrated would be most effective in its intended purpose?

Can you think of an experimental design you could use to answer this problem? Would precipitation work? Or crystallization? You could precipitate the active ingredient in the different lotions and compare the masses. But there are other possible methods as well.

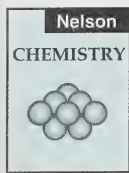
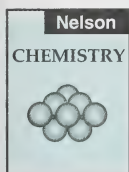


Table 7.3 on page 193 of your textbook gives a description of some different experimental procedures. Study this table and answer the following question.

1. Match each of the following statements to the correct term.

Description	Term
a. titrant is added to a measured volume of solution	i. crystallization
b. formed solid is filtered	ii. gas collection
c. temperature, pressure, and volume of gas produced is measured	iii. titration
d. solvent is vaporized from a solution and mass of the solid is measured	iv. filtration



Chemical analysis techniques can incorporate one design or a combination of the four experimental designs mentioned in Table 7.3. Some analytical techniques are mentioned in the margin of page 193 in your textbook. Answer the following question after reading this information.

2. Name the four chemical analysis techniques.

Check your answers by turning to the Appendix, Section 3: Activity 2.

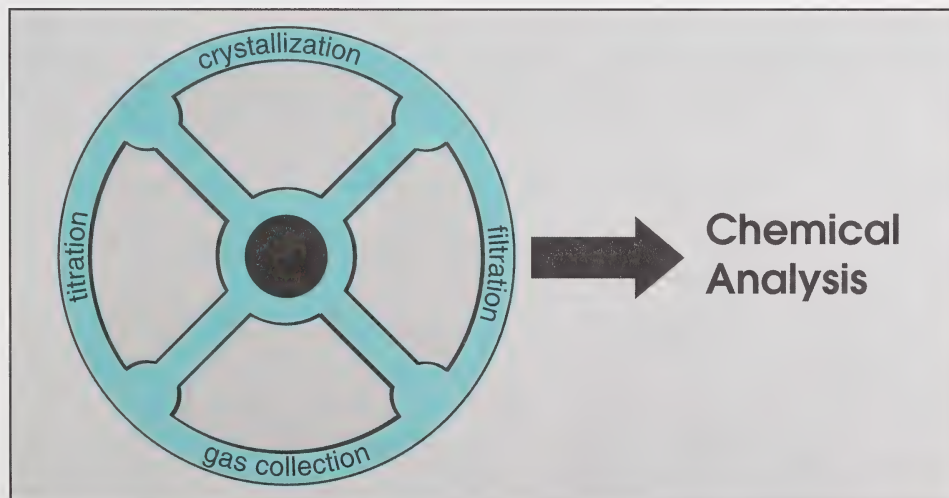
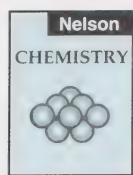


FIGURE 4.6: Experimental Designs for Chemical Analysis



How can you decide that one chemical analysis procedure is better than another for solving the same problem? To learn the criteria used to evaluate experimental designs, you will be doing Lab Exercises 7I, 7J, and 7K on pages 193 and 194 in your textbook. These exercises illustrate how the same problem can be solved using different experimental designs. Read the Lab Exercises and then complete the following three questions.

Science Skills

- ☒ A. Initiating
- ☐ B. Collecting
- ☒ C. Organizing
- ☒ D. Analysing
- ☐ E. Synthesizing
- ☒ F. Evaluating

3. Lab Exercise 7I: Filtration Analysis

(You used this procedure when you collected the precipitate calcium carbonate in Section 1 of this module).

- a. List all the equipment and materials needed.
- b. For your analysis, determine the concentration of the hydrochloric acid. Show all calculations.

Check your answers by turning to the Appendix, Section 3: Activity 2.

Science Skills

- ☒ A. Initiating
- ☐ B. Collecting
- ☒ C. Organizing
- ☒ D. Analysing
- ☐ E. Synthesizing
- ☒ F. Evaluating

4. Lab Exercise 7J: Gas Volume Analysis

(You studied the properties of gases in Module 2 and did an investigation in Module 3 to test an experimental design for the universal gas constant.)

- a. List the materials and equipment required.
- b. For your analysis, show your calculations of the hydrochloric acid concentration.

Check your answers by turning to the Appendix, Section 3: Activity 2.

Science Skills

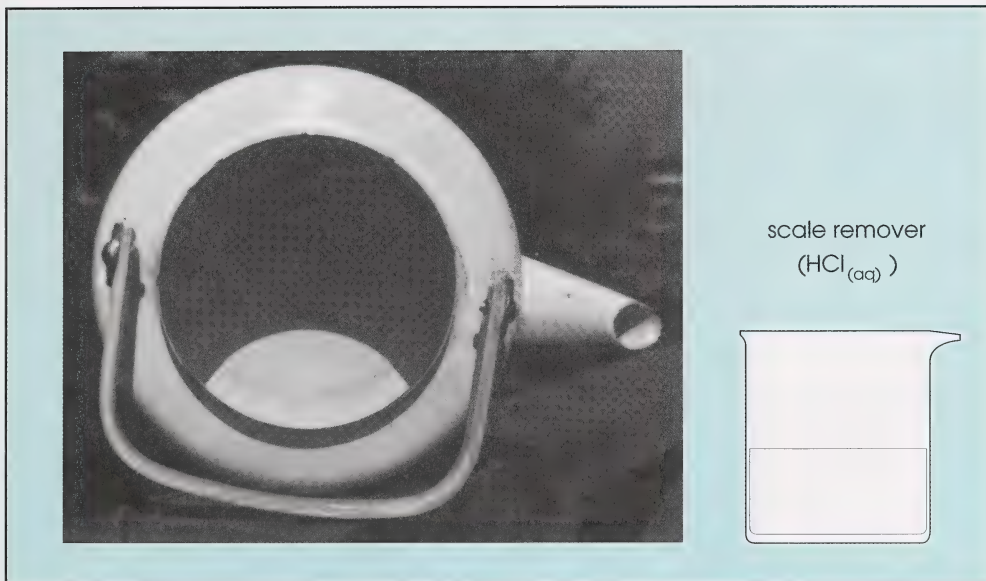
- ☒ A. Initiating
- ☐ B. Collecting
- ☒ C. Organizing
- ☒ D. Analysing
- ☐ E. Synthesizing
- ☒ F. Evaluating

5. Lab Exercise 7K: Titration Analysis

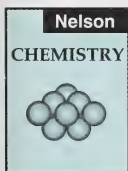
(You used volumetric technique in Section 2 of this module in determining the concentration of an acid.)

- a. List the materials and equipment needed.
- b. For your analysis calculate the hydrochloric acid concentration.

Check your answers by turning to the Appendix, Section 3: Activity 2.



Compare the three values of concentration you have calculated for the hydrochloric acid kettle cleaner. Why are they different? Is it because one design is better and therefore more precise?



To evaluate the experimental designs of Lab Exercises 7I, 7J, and 7K, read the section Evaluating Experimental Designs on page 195 of *Nelson Chemistry*.

6. Do question 44 (a, b) from page 195 of your textbook.

Check your answers by turning to the Appendix, Section 3: Activity 2.

Now that you have learned how to evaluate different designs, what applications are there for this process? Can you think of any industrial applications?

Industrial Applications

catalyst – a substance that speeds up the rate of a reaction and is not used up

Industrial plants which manufacture ethylene use a **catalyst** for a high efficiency rate. The catalyst usually contains very small amounts of impurities in the form of elemental Mg, Al, or Ti. A small amount of contamination does not effect the performance of the catalyst. What do you think would happen if the catalyst gets contaminated with higher than usual levels of impurities? Just like using leaded gas for your car destroys the catalytic convertor of the car due to lead contamination, similarly a highly contaminated industrial catalyst will result in machinery breakdown. Samples of the catalyst are sent periodically to the lab to check for percentages of impurities.

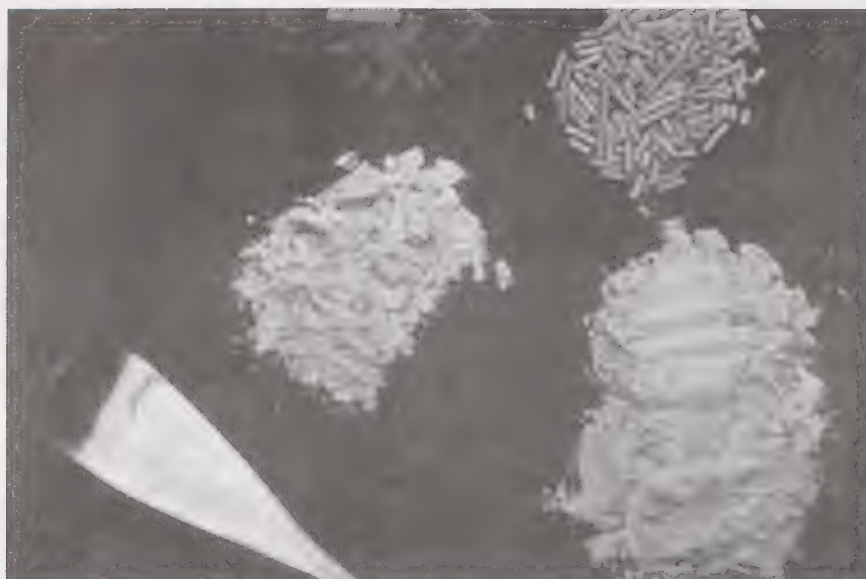


FIGURE 4.7: Various Catalysts

AOSTRA

In the following descriptions, you are given two experimental designs that attempt to calculate the mass of magnesium in a catalyst. Complete the analysis and then evaluate your evidence to suggest which procedure has a better design.

Science Skills

- ☐ A. Initiating
- ☐ B. Collecting
- ☐ C. Organizing
- ☒ D. Analysing
- ☐ E. Synthesizing
- ☒ F. Evaluating

Design A

Problem

What mass of magnesium is present in a catalyst used for ethylene production in a chemical plant?

Experimental Design

A quantity of 0.100 mol/L carbonic acid ($\text{H}_2\text{CO}_{3(\text{aq})}$) is reacted with a 10.0 mg sample of catalyst to form a precipitate. The precipitate is filtered and dried.

Evidence

Volume of the acid (mL) = 50.0

Mass of filter paper (g) = 0.90

Mass of filter paper and precipitate (g) = 1.98

7. Complete the analysis for this investigation by calculating the mass of magnesium in the sample. Show all calculations.

Check your answers by turning to the Appendix, Section 3: Activity 2.

Science Skills

- ☐ A. Initiating
- ☐ B. Collecting
- ☐ C. Organizing
- ☒ D. Analysing
- ☐ E. Synthesizing
- ☒ F. Evaluating

Design B

Problem

What mass of magnesium is present in a catalyst used for ethylene production in a chemical plant?

Experimental Design

The catalyst sample is first treated with an acid to react and dissolve any magnesium present. The solution is made basic, then titrated with 0.10 mol/L EDTA. This chemical reacts preferentially with magnesium in a one to one mole ratio.

Evidence

EDTA – ethylenediamine-tetraacetate; substance used in many titrations as a titrant

Titration of 10.0 mL Sample with 0.10 mol/L EDTA			
Trial	1	2	3
Final buret reading (mL)	10.0	12.1	20.1
Initial buret reading (mL)	6.0	8.0	16.0
Volume of EDTA used (mL)	4.0	4.1	4.1
Average volume used (mL)			

8. Complete the analysis for this investigation.
- Calculate the average volume of EDTA used.
 - Calculate the mass of magnesium in the sample. Show all calculations.

Check your answers by turning to the Appendix, Section 3: Activity 2.

9. Compare the analyses of the two designs. Which design is best suited for determining the concentration of magnesium in the catalyst? Justify your opinion.

Check your answers by turning to the Appendix, Section 3: Activity 2.

The type of experimental designs discussed so far are used in different types of chemistry labs. But experimental designs are procedures that can be used to solve any problem. For example, engineers are constantly involved in designing new industrial plants using new technologies to meet changing environmental regulations.

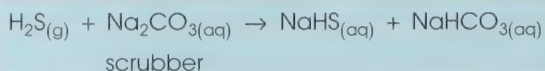
Alberta has a number of industrial plants that process natural gas. Have you ever wondered what gases are present in the smokestack emissions from these refineries? Gases like hydrogen sulphide and sulphur dioxide combine with the water in the atmosphere to form acid rain.



WESTFILE INC.

New technology has led to changes in plant designs. Today these gases can be collected and used to make by-products to be sold for profit.

One such plant is in Caroline, Alberta. Alkaline scrubbers packed in towers remove hydrogen sulphide gas.



The $\text{H}_2\text{S}_{(\text{g})}$ is recovered and oxidized to elemental sulphur ($\text{S}_{8(\text{s})}$) and sold to other industries.

10. What would the impact on the environment be if the gas plant design did not incorporate scrubbing towers?

Check your answers by turning to the Appendix, Section 3: Activity 2.

Can you think of some uses of sulphur? Refer to the Module 1 Appendix and Module 2 for finding a variety of sulphur uses.

In this activity you have learned that a chemical analysis problem can be solved using different experimental designs. Each design can be evaluated using the same criteria. The best experimental design is the one that meets most criteria and solves the problem.

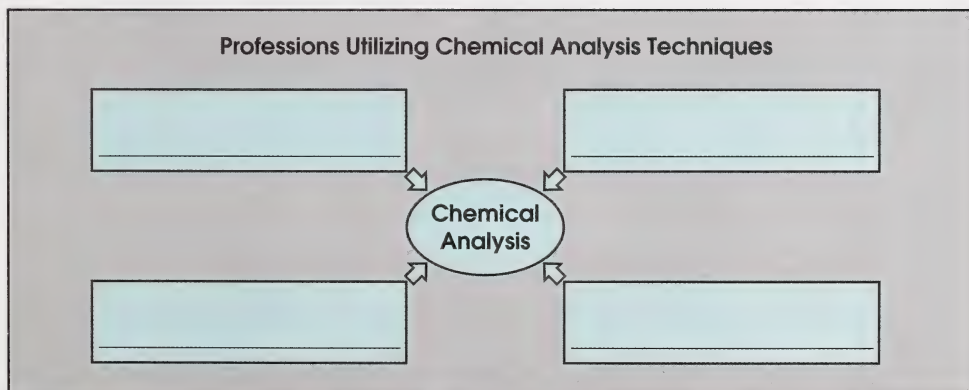
ACTIVITY

3

Careers and Chemistry

Throughout this module you have seen several references to industry and society where quantitative analysis techniques are used. Many careers relate to these various applications.

1. Fill in the following diagram using the various examples given in this module of professions in industry and society that use the chemical analysis techniques.



Check your answers by turning to the Appendix, Section 3: Activity 3.

Many of the chemical analysis techniques discussed so far are used in law enforcement. Forensic chemists are constantly working with various analysis processes to determine the identity of materials found as evidence at a crime scene.

As optional enhancement, if you have access to the laser videodisc *Cosmic Chemistry*, find and view the individual frames 784-798, chapter 2, side 6. These still frames illustrate various aspects of forensic chemistry, from the types of technology used to the identification of various materials.

Examples



Frame 784

Frame 784 – illustrates a gas chromatograph-mass spectrometer



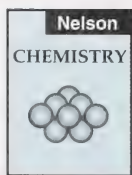
Frame 787

Frame 787 – shows a thin layer chromatography plate that is used for the separation of drugs, poisons, and dyes



Frame 789

Frame 789 – illustrates a fibre match using a comparison microscope



science – the describing and explaining of natural phenomena through a body of knowledge that can be experimentally tested by others

A career in forensic chemistry would offer an exciting opportunity for anyone interested in **science** and in solving puzzles. Read page 173 of your textbook for an account of forensic chemist, Carolyn Krausher.

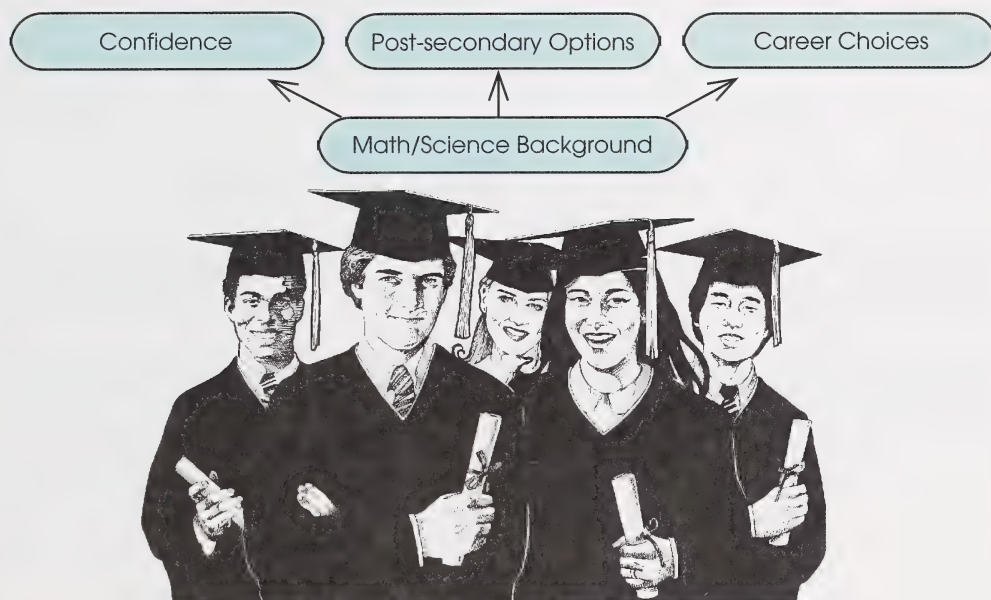
2. a. What does the term *forensic* relate to?
- b. List four types of technology that Carolyn relies on in the various analyses she performs.
- c. List three types of duties Carolyn performs.
- d. What type of educational background does Carolyn have?
- e. What advice does Carolyn give to high school students interested in chemistry?

Check your answers by turning to the Appendix, Section 3: Activity 3.

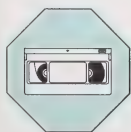
As you discovered in the preceding career profile, a good background in mathematics and the various sciences is important.

A broad scientific background will help you in several ways:

- You will be more literate and more confident in handling situations in the ever-changing world.
- It will enable you to choose from a wide range of disciplines if you are interested in attending a post-secondary institution.
- It will give you more flexibility in career choices.



You would probably find it most helpful hearing from other people in various fields for helping you make choices in your education. The following video gives a profile of four people in science fields and also gives advice on educational backgrounds.



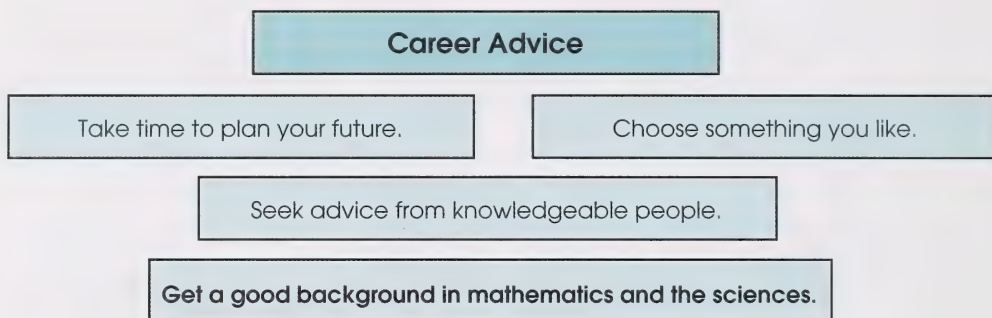
View the video *Choosing Science (Senior High Science Series)* and answer the following questions. You may find it helpful to preview the questions before watching the video.

3. List the occupations of the four people profiled in the video.
4. Even though the people in the video have varied backgrounds, what is a common recommendation they give regarding the educational background for high school students?

5. The video stresses that there are many approaches to common areas of interest. What two pieces of advice are described that would help you approach your career choice?

Check your answers by turning to the Appendix, Section 3: Activity 3.

One of the toughest decisions you will make in life will be your career choice and subsequent educational needs. Give yourself the greatest advantage by having as strong a high school background as possible.

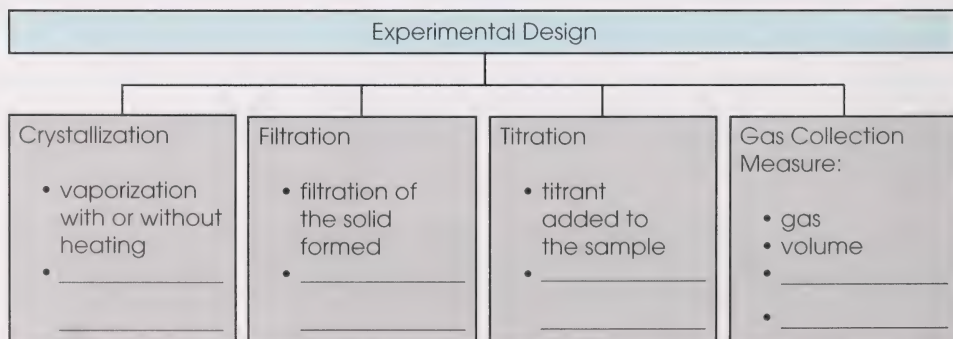


Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

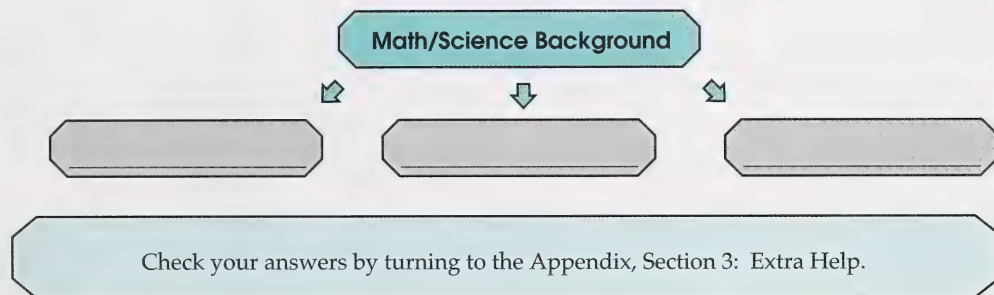
1. Review the main objectives of this section by filling in the missing information in each box.



2. Use the given words to complete the following sentences that discuss some criteria used for evaluating experimental designs.

- low • responding • variable
- control group • environment • cost

- a. Only one _____ should be manipulated at a time.
 - b. The _____ of performing the experiment should be as _____ as possible.
 - c. The _____ variable should be observed consistently.
 - d. The design should include a _____ _____.
 - e. The design should have little adverse effect on the _____.
3. Fill in the missing information on how a broad math/science background would help you in your future endeavours.



Enrichment

Do any **one** of the following.

1. Investigate the design used for determining chlorine concentration in your water supply. Evaluate this design based on the criteria you learned in this section.
2. Investigate the need for desalinization (salt removal) and the different methods by which water can be desalinized. Compare the advantages and disadvantages of these methods.
3. Research the use of catalytic incinerators in refinery plants and comment on their advantages and disadvantages.

Check your answers by turning to the Appendix, Section 3: Enrichment.

Conclusion

You have learned the significance of designing a good experimental procedure for solving not only problems in chemical analysis but also in industrial designs. The criteria for evaluating a design can be applied to disciplines other than science. You have also seen how a good background in science gives you the greatest choices possible in your future career.

Assignment
Booklet

ASSIGNMENT

Turn to Assignment Booklet 4B and do the assignment for Section 3.

MODULE SUMMARY

Principles of stoichiometry form the basis of quantitative analysis. Chemical analysis techniques are not only valuable in research labs, but are applied widely in industry for quality control, research, and development. Procedures designed for solving technological and scientific problems are evaluated based on a set of criteria. Designs that fit the criteria are used for solving problems.



Appendix



Glossary
Suggested
Answers

Glossary

activated charcoal: charcoal powder treated with chemicals to increase adsorption properties

adsorb: adhere or hold a thin layer of molecules (gases, liquids, or solutes) to the surface of a solid or liquid

catalyst: a substance that speeds up the rate of a reaction and is not used up

crystallization: a technique involving crystal formation by vaporizing the solvent

dilution: decreasing the concentration of a solution by increasing the amount of solvent

EDTA: ethylenediaminetetraacetate; substance used in many titrations as a titrant

endpoint: the point at which there is a sudden change in the property of the solution when a reaction is complete

excess reagent: the reactant that is not completely consumed when a reaction is taken to completion

extrapolating: taking values from outside the bounds of the given data

fractional distillation: a method of separating the components of a mixture based on the components' different boiling points

interpolating: taking values from inside the bounds of the given data

intragastic: inside the stomach

limiting reagent: the reactant that is completely consumed when a reaction is taken to completion

limnology: the scientific study of the physical, chemical, and biological conditions in fresh waters

precipitate: an insoluble substance formed as a result of a chemical reaction in solution

precipitation reaction: a reaction in which an insoluble substance forms and separates from solution

quantitative analysis: the analysis of a sample to find the quantity of a specific substance present

salt: an ionic compound, usually white in appearance, which contains neither H^+ or OH^- ions

science: the describing and explaining of natural phenomena through a body of knowledge that can be experimentally tested by others

technology: the application of scientific knowledge for solving practical problems

titrant: the solution added from the buret during a titration procedure

titration: the process of progressively adding a precise volume of one solution from a buret to a known volume of another solution in a flask

Suggested Answers

Section 1: Activity 1

1. The results of a quantitative analysis show the precise amount of each substance present, whereas a qualitative analysis shows which substances are present.

2. Two important aspects of quantitative analysis are the following:

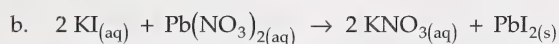
- general empirical knowledge
- problem-solving skills

3. A limiting reagent is the reactant in a chemical reaction that is completely used up.

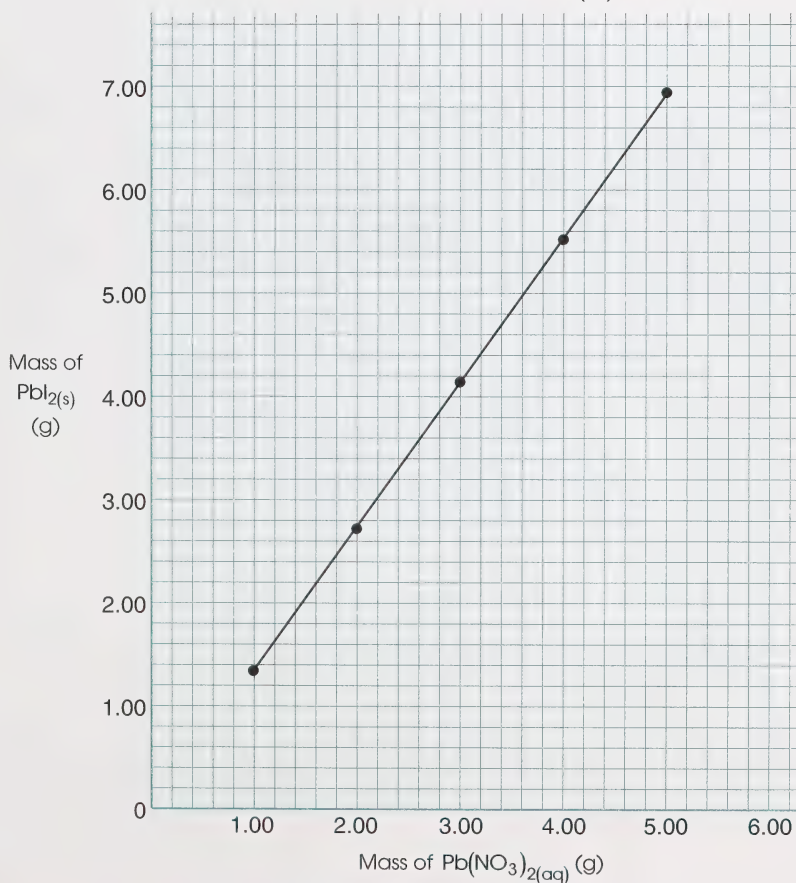
4. Ginger ale is the limiting reagent in the recipe. All the other ingredients have an excess supply.

5. a.

Data	Solution 1	Solution 2
mass of the filter paper plus precipitate	5.39 g	8.57 g
– mass of the filter paper	0.99 g	1.02 g
mass of the precipitate	4.40 g	7.55 g



c. Relationship Between Mass of $\text{Pb}(\text{NO}_3)_{2(\text{aq})}$ and $\text{PbI}_{2(\text{s})}$



6. The answers can be obtained by using the mass of precipitate and the graph.

Solution 1: The mass of lead(II) nitrate present in the solution is 3.18 g (± 0.05 g).

Solution 2: The mass of lead(II) nitrate present in the solution is 5.40 g (± 0.05 g).

7. Lead(II) nitrate is the limiting reagent because the mass of the precipitate produced is dependent upon the amount of lead nitrate in the solution. The lead(II) nitrate reacts completely.
8. Once the precipitate formed has settled and a clear solution remains at the top, a few more drops of potassium iodide should be added to the mixture. If the solution becomes cloudy, repeat the procedure until addition of $KI_{(aq)}$ does not produce any cloudiness.
9. **Textbook question 1:**

Quantitative chemical analysis is used to determine the amount of a substance in a given sample.

Textbook question 2:

Graphs are useful in hospital, commercial, or industrial laboratories. Technicians use graphs to read the required quantity of a chemical by extrapolating (taking values from outside the bounds of the given data) or interpolating (taking values from inside the bounds of the given data) the plotted information. See Figure 4.8.

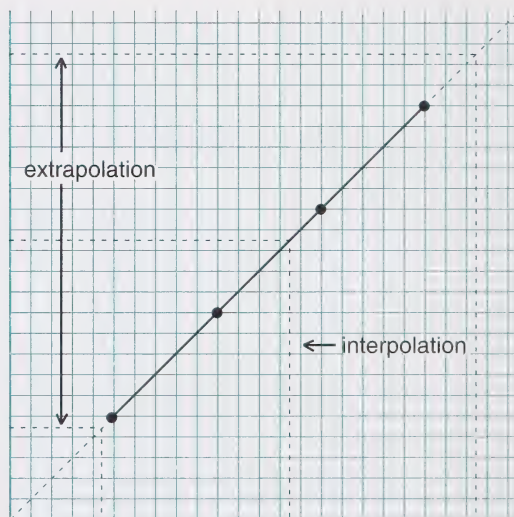


FIGURE 4.8: Extrapolation and Interpolation

Textbook question 3:

The manipulated variable is the mass of lead(II) nitrate.

The responding variable is the mass of PbI_2 precipitate.

10. a. The ratios involved are as follows:

Methane and steam react in the ratio of 1:2, that is, 1 mole of methane:2 moles of steam.

- b. Methane is the limiting reagent.

11. Textbook question 7:

Science	Technology
Science is an international discipline.	Technology is localized.
Science is theoretical in its approach.	Technology is empirical.
The evaluation of ideas is based on ability to predict and explain natural phenomena.	Evaluation is based on simplicity, efficiency, and cost effectiveness.
Science emphasizes ideas.	Technology emphasizes methods and materials.

Textbook question 8:

- | | |
|---------------|---------------|
| a. technology | d. technology |
| b. science | e. science |
| c. science | f. technology |

Section 1: Activity 2

- A pin prick usually takes three to six minutes to stop bleeding.
- Materials required for this investigation include the following:

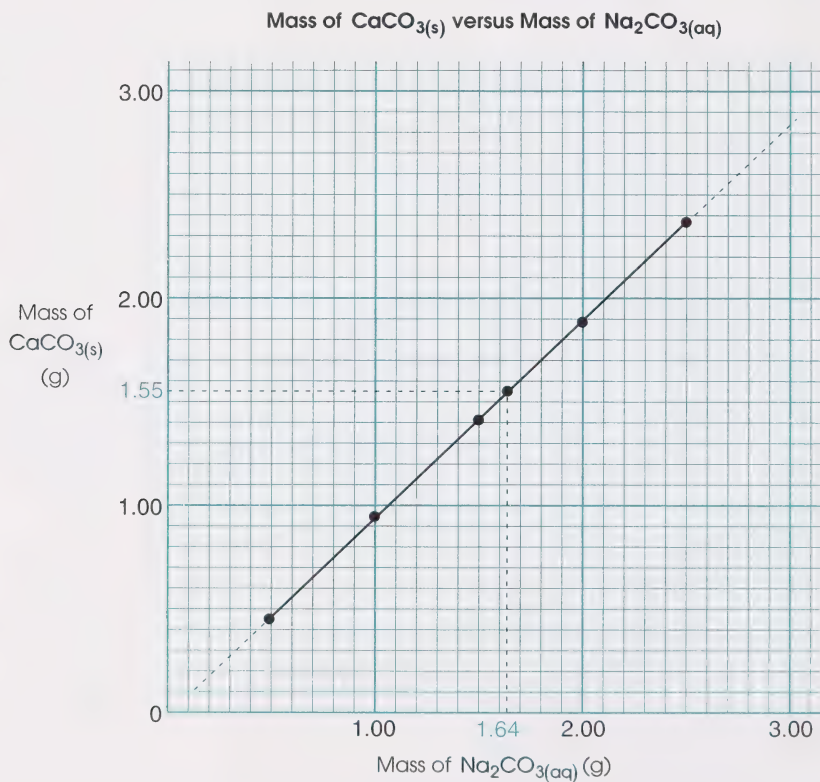
• 50.0 mL sample of sodium carbonate solution • 60.0 mL sample of 0.10 mol/L calcium chloride solution • filter paper • funnel • beaker	• stirring rod • stand with funnel clamp • watch glass • balance
---	---
- The following steps are to be followed in this investigation:
 - Pour an equal volume (50.0 mL) of 0.10 mol/L $\text{CaCl}_{2(\text{aq})}$ into 50.0 mL of the $\text{Na}_2\text{CO}_{3(\text{aq})}$ solution.
 - When the precipitate has settled and a clear solution remains on the top, add a few drops of $\text{CaCl}_{2(\text{aq})}$ to the mixture of solutions.
 - If cloudiness appears, add more $\text{CaCl}_{2(\text{aq})}$ until no more precipitate forms.
 - Record the mass of the filter paper.
 - Filter the solution following correct filtration procedure.
 - Dry the precipitate on a watch glass.
 - Record the mass of the filter paper and the precipitate.

4. An example of the observations may be shown as follows:

Volume of $\text{CaCl}_{2(\text{aq})}$ used (mL)	= 50.0
Volume of $\text{Na}_2\text{CO}_{3(\text{aq})}$ used (mL)	= 50.0
Mass of filter paper (g)	= 0.99
Mass of filter paper and precipitate (g)	= 2.54

5. The analysis of the investigation may be developed as follows:

- a. The reference graph is illustrated here:



- b. The mass of precipitate ($\text{CaCO}_{3(\text{s})}$) was $2.54 \text{ g} - 0.99 \text{ g} = 1.55 \text{ g}$. The mass of sodium carbonate is then found from the graph as shown in 5. a. The mass of sodium carbonate in the sample is 1.64 g.
- c. The concentration of the sodium carbonate solution used may be calculated as follows:

$$C_{(\text{Na}_2\text{CO}_3)} = 1.64 \text{ g Na}_2\text{CO}_3 \times \frac{1 \text{ mol}}{105.99 \text{ g Na}_2\text{CO}_3} \times \frac{1}{0.0500 \text{ L}}$$

$= 0.309 \text{ mol/L}$ The concentration of Na_2CO_3 solution is 0.309 mol/L.

6. The dissociation equation for sodium carbonate solution may be written as follows:



7. The concentration of Na^+ in the solution may be determined as follows:

$$C_{(\text{Na}^+)} = \frac{0.309 \text{ mol Na}_2\text{CO}_3}{1 \text{ L}} \times \frac{2 \text{ mol Na}^+}{1 \text{ mol Na}_2\text{CO}_3}$$

$$= 0.618 \text{ mol/L Na}^+ \quad \text{The concentration of sodium ions is 0.618 mol/L.}$$

The concentration of CO_3^{2-} in the solution may be determined as follows:

$$C_{(\text{CO}_3^{2-})} = \frac{0.309 \text{ mol Na}_2\text{CO}_3}{1 \text{ L}} \times \frac{1 \text{ mol CO}_3^{2-}}{1 \text{ mol Na}_2\text{CO}_3}$$

$$= 0.309 \text{ mol/L CO}_3^{2-} \quad \text{The concentration of CO}_3^{2-} \text{ ions is 0.309 mol/L.}$$

8. a. Calcium chloride is in excess.
- b. Add a few drops of $\text{CaCl}_{2(\text{aq})}$ to the solution mixture of $\text{Na}_2\text{CO}_{3(\text{aq})}$ and $\text{CaCl}_{2(\text{aq})}$. If no cloudiness appears, more $\text{CaCl}_{2(\text{aq})}$ is not needed. If cloudiness appears, continue to add more $\text{CaCl}_{2(\text{aq})}$ until all the $\text{Na}_2\text{CO}_{3(\text{aq})}$ has reacted.

9.

Amount $\text{CaCO}_{3(\text{s})}$ Produced	Mass $\text{Na}_2\text{CO}_{3(\text{aq})}$ Reacted	Extrapolation or Interpolation
1.30 g	1.38 g (± 0.05 g)	interpolation
2.80 g	2.96 g (± 0.05 g)	extrapolation

10.

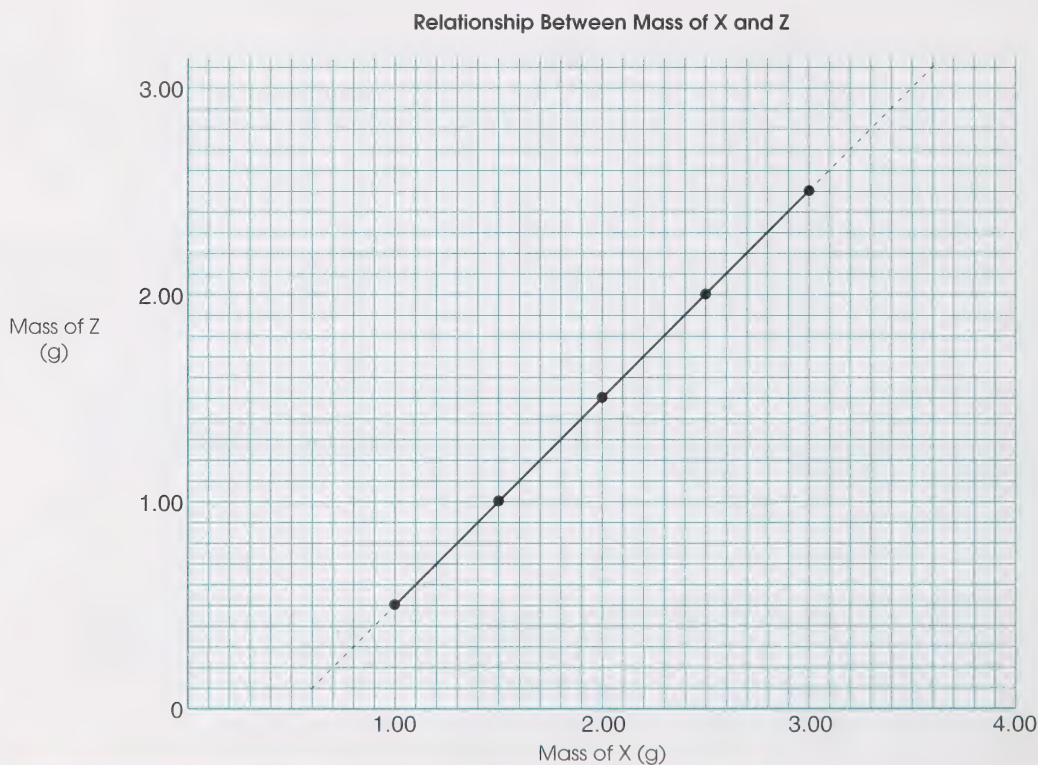
Amount $\text{Na}_2\text{CO}_{3(\text{aq})}$ Reacted	Mass $\text{CaCO}_{3(\text{s})}$ Produced	Extrapolation or Interpolation
2.75 g	2.60 g (± 0.05 g)	extrapolation
0.90 g	0.83 g (± 0.05 g)	interpolation

Section 1: Follow-up Activities

Extra Help

1. a. Some of the most important measurements in chemistry are **stoichiometric** measurements.
- b. These measurements are important because they show the **proportions** in which various substances react.

- c. In this section you used the stoichiometry of **precipitation** reactions for **quantitative analysis**. This method requires mixing solutions of ionic compounds. The new combination of ions may produce a substance which may not dissolve appreciably in water, and therefore settles as a solid. This solid is called a **precipitate**.
- d. **Graphs** prepared in advance from **reference data** can be used to predict the mass of a substance in a sample of a solution. They can show the relationship between different masses of the low solubility substance and the **solute** in the original sample solution.
2. a. False (Since the concentrations of the reagents may be different, the volumes may need to be different as well to cause a complete reaction. The reacting ratios may also be different.)
- b. False (A few drops of the excess reagent are added to the precipitate mixture.)
- c. True
3. a.



b.

Mass of Z Produced (g)	Mass of X Reacted (g)
0.75	1.25
0.80	1.30
1.20	1.70
1.95	2.45
2.90	3.40

- c. The limiting reagent is X.
- d. The mass of Z is the responding variable.

Enrichment

1. Answers to this activity will vary. The following is a sample response. You could choose from any one of the following laboratories:

- industrial, e.g., water waste treatment plant
- medical
- pharmaceutical
- university research

Prepare a sample questionnaire that you will use to interview the laboratory technician.

A sample questionnaire follows. You may find it useful for your research.

Before the visit you should phone the technician and explain the purpose of your research. Ask the technician the first question on the questionnaire. If the answer is yes, set up a time for the interview and inform the person about the approximate time it will take to complete the interview. You will need to interview more than one technician.

Sample Questionnaire

Answer each question by checking the appropriate box.

1. Are you familiar with the technique of finding the concentration of a sample solution by using the mass of the precipitate formed when aqueous salt solutions are mixed?
☐ Yes ☐ No
2. What method of analysis do you use?
☐ computer ☐ reference graphs
☐ mathematical calculations ☐ other (please explain)
3. On how many samples of solutions do you use this technique per day?
☐ 0-3 ☐ 4-6
☐ 7-10 ☐ more than 10
4. How easy do you find it to use this technique?
☐ very easy ☐ some difficulty ☐ very difficult
5. Do you find this technique a useful tool?
☐ very useful ☐ somewhat useful ☐ not useful
6. Give a reason for your choice in question 5.

After the interview, don't forget to thank the person. Evaluate the results of your data. Charts similar to the following may be used to summarize your responses.

Questionnaire Question:

- | # of Yes | # of No |
|----------|---------|
| | |
- | | |
|---------------------------|--|
| computers | |
| reference graphs | |
| mathematical calculations | |
| other methods | |
- | | |
|------|--|
| 0-3 | |
| 4-6 | |
| 7-10 | |
| 10+ | |
- | | |
|-----------------|--|
| very easy | |
| some difficulty | |
| very difficult | |
- | | |
|-----------------|--|
| very useful | |
| somewhat useful | |
| not useful | |

Summarize your analysis and write a paragraph relating the results of the analysis to the information in the module.

2. Normal glucose concentration in whole blood ranges from 65 to 95 mg / 100 mL. Benedict's reagent contains the following chemicals:

$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	copper(II) sulphate pentahydrate
$\text{Na}_3\text{C}_6\text{H}_5\text{O}_7 \cdot 2\text{H}_2\text{O}$	sodium citrate
Na_2CO_3	sodium carbonate

The procedure used in the laboratories to test urine samples for the presence of glucose involves:

- Add 8 drops of urine to 5 mL of Benedict's reagent in a test tube.
- Place the test tube in a water bath for 3 minutes.

An analysis is done using the following table.

Appearance	Report	Approximate Glucose Concentration (g/100 mL)
blue to green, no precipitate	0	0-0.1
green with yellow precipitate	1+	0.3
olive green	2+	1.0
brownish-orange	3+	1.5
brick-red	4+	2.0 or more

A convenient adaptation of the preceding procedure is marketed in tablet form. The tablets contain anhydrous cupric sulphate, sodium hydroxide, citric acid, and sodium bicarbonate. One tablet is mixed with 5 drops of urine and allowed to stand for 15 seconds. The mixture is observed for colour change. Heat is generated by the sodium hydroxide in the tablet when it contacts the water. This makes the use of the water bath unnecessary.

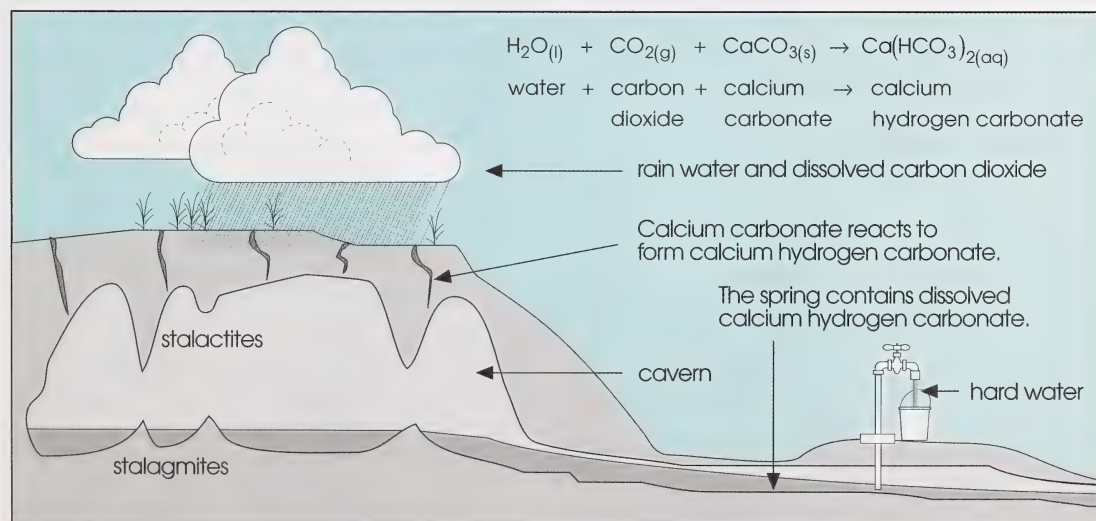
- Hardness in the water is caused by dissolved calcium and magnesium compounds such as calcium hydrogen carbonate, calcium sulphate, or magnesium sulphate. These substances are not removed at the water treatment plants.

Calcium hydrogen carbonate is formed when rain falls on limestone rocks. Limestone is mostly calcium carbonate, which is insoluble in water.

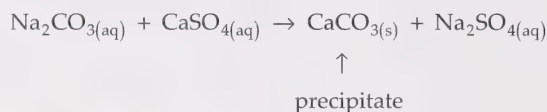
Rainwater is a weak acid solution due to gases like CO_2 dissolved in it. This solution attacks the CaCO_3 , forming $\text{Ca}(\text{HCO}_3)_2$, which is soluble in water.

Other compounds that cause hardness are dissolved by rain from rocks such as dolomite ($\text{CaCO}_3 \cdot \text{MgCO}_3$) and gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$).

The following is a schematic representation of how hard water is produced.



Sodium carbonate is added to water to remove hardness by precipitating calcium carbonate, as shown in the following equation:



The water softening industries determine the degree of hardness in the water and use stoichiometric principles to calculate the amount of Na_2CO_3 needed to precipitate the CaSO_4 .

Section 2: Activity 1

1. Concentration refers to the amount of solute in a given amount of solution.

2. Units used to communicate concentration include the following:

- mol/L
- ppm
- % by volume
- g/L, mg/L, etc.

3. The relationship used to calculate molar concentration is the following:

$$\text{Molar concentration} = \frac{\text{moles of solute}}{\text{volume of solution in litres}} \quad \text{or} \quad C = \frac{n}{v}$$

4. The final concentration may be calculated as follows:

$$C = \frac{20 \text{ mL acetone}}{100 \text{ mL of solution}} \times 100\% = 20\% \text{ by volume}$$

5. a. $\text{Concentration} = \frac{\text{weight of solute}}{\text{volume of solution}} \xrightarrow{\text{actually}} \frac{\text{mass}}{\text{volume}} = \frac{m}{v}$

b. The units for expressing this relationship are g/L or mg/L.

6. **Textbook question 12:**

$$7\% \text{ by volume} \rightarrow \frac{7 \text{ mL}}{100 \text{ mL}}$$

$$v_{(\text{CH}_3\text{COOH})} = 250 \text{ mL} \times \frac{7 \text{ mL}}{100 \text{ mL}}$$

$$= 17.5 \text{ mL}$$

$$= 2 \times 10^1 \text{ mL (rounded off)}$$

The volume of pure solute is 2×10^1 mL.

Textbook question 13:

$$m_{(\text{NaCl})} = 60 \text{ kg} \times \frac{25 \text{ kg}}{100 \text{ kg}}$$

$$= 15 \text{ kg}$$

The mass of salt dissolved is 15 kg.

Textbook question 14:

$$\begin{aligned}
 m_{(\text{PCBs})} &= 64 \text{ kg} \times \frac{4.0 \text{ mg}}{1 \text{ kg}} \\
 &= 256 \text{ mg} \\
 &= 2.6 \times 10^2 \text{ mg}
 \end{aligned}$$

The mass of PCBs present in a 64 kg person is $2.6 \times 10^2 \text{ mg}$.

7. $93\% \text{ W/v} = 93 \text{ g/100 mL}$

$$\begin{aligned}
 m_{(\text{C}_2\text{H}_5\text{OH})} &= 25 \text{ mL} \times \frac{93 \text{ g}}{100 \text{ mL}} \\
 &= 23 \text{ g}
 \end{aligned}$$

The mass of ethanol present is 23 g.

8. $24 \text{ ppm} = \frac{24 \text{ mg}}{1 \text{ kg}}$

$$\begin{aligned}
 m_{(\text{Mg})} &= \frac{24 \text{ mg}}{1 \text{ kg}} \times 0.500 \text{ kg}^* \\
 &= 1 \times 10^1 \text{ mg}
 \end{aligned}$$

(*1 mL = 1 g for water at room temperature)

9. Textbook question 16:

$$\begin{aligned}
 v_i C_i &= v_f C_f \\
 v_i \times \frac{17.8 \text{ mol}}{\text{L}} &= 2.00 \text{ L} \times \frac{0.200 \text{ mol}}{\text{L}} \\
 v_i &= 0.0225 \text{ L or } 22.5 \text{ mL}
 \end{aligned}$$

The volume required is 0.0225 L or 22.5 mL.

Textbook question 17:

$$\begin{aligned}
 v_i C_i &= v_f C_f \\
 1.00 \text{ L} \times \frac{17.4 \text{ mol}}{\text{L}} &= v_f \times \frac{0.400 \text{ mol}}{\text{L}} \\
 v_f &= 43.5 \text{ L}
 \end{aligned}$$

The volume of solution prepared is 43.5 L.

Textbook question 15:

$$\begin{aligned}
 v_{(\text{NH}_3)} &= \frac{1 \text{ L}}{1.24 \text{ mol}} \times 0.500 \text{ mol} \\
 &= 0.403 \text{ L}
 \end{aligned}$$

The volume of solution would be 0.403 L.

Textbook question 18:

$$\begin{aligned}
 v_i C_i &= v_f C_f \\
 1 \text{ L} \times 72\,786 \text{ ppm} &= v_f \times 345 \text{ ppm} \\
 v_f &= 2 \times 10^2 \text{ L or } 0.2 \text{ kL}
 \end{aligned}$$

The volume that the CO_2 emission must be diluted to is 0.2 kL.

Textbook question 19:

$$\begin{aligned}
 v_i C_i &= v_f C_f \\
 0.01000 \text{ L} \times C_i &= 0.2500 \text{ L} \times \frac{0.274 \text{ g}}{\text{L}} \\
 C_i &= 6.85 \frac{\text{g}}{\text{L}}
 \end{aligned}$$

The concentration of the solution was $6.85 \frac{\text{g}}{\text{L}}$.

Section 2: Activity 2

1.
 - a. False (The solution in the buret is the titrant.)
 - b. True
 - c. False (It indicates the endpoint.)
 - d. True
 - e. False (It is called the equivalence point.)
2.
 - a. stand (retort stand)
 - b. Erlenmeyer flask
 - c. buret clamp
 - d. buret
3. The following materials are also required for a titration:
 - pipet
 - pipet bulb
 - funnel
 - bottle of distilled water
 - beaker*
 - volumetric flask with cap*
 - balance*
 - weigh boat*

***Note:** These pieces of equipment would be needed for the preparation of the standard solution in the volumetric flask.

4. The volume of the solution used is 23.6 mL ($v_f - v_i = 28.2 \text{ mL} - 4.6 \text{ mL} = 23.6 \text{ mL}$).

5. a.

Titration of 10.00 mL of $\text{HCl}_{(\text{aq})}$ with 0.10 mol/L $\text{KOH}_{(\text{aq})}$			
Trial	1	2	3
Final buret reading (mL)	10.8	15.2	13.6
Initial buret reading (mL)	0.50	5.0	3.2
Volume of $\text{KOH}_{(\text{aq})}$ used (mL)	10.3	10.2	10.4

$$\text{b. Average volume} = \frac{10.3 \text{ mL} + 10.2 \text{ mL} + 10.4 \text{ mL}}{3} = 10.3 \text{ mL}$$

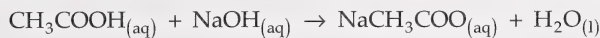
The average volume of potassium hydroxide used is 10.3 mL.

6. Trial #1 is probably flawed because its value is quite different from the other trials.

$$7. \text{ Average volume} = \frac{13.0 \text{ mL} + 12.9 \text{ mL} + 13.1 \text{ mL}}{3} = 13.0 \text{ mL}$$

The average volume $\text{NaOH}_{(\text{aq})}$ used is 13.0 mL.

8. The equation for the reaction between vinegar and sodium hydroxide is as follows:



9. a. $n_{(\text{NaOH})} = 13.0 \text{ mL} \times \frac{0.202 \text{ mol NaOH}}{1 \text{ L}}$
 $= 2.63 \text{ mmol NaOH}$ The number of moles reacted is 2.63 mmol NaOH.
- b. $n_{(\text{CH}_3\text{COOH})} = 2.63 \text{ mmol NaOH} \times \frac{1 \text{ mol CH}_3\text{COOH}}{1 \text{ mol NaOH}}$
 $= 2.63 \text{ mmol CH}_3\text{COOH}$ The number of moles of vinegar reacted is 2.63 mmol.
- c. $C_{(\text{CH}_3\text{COOH})} = 2.63 \text{ mmol CH}_3\text{COOH} \times \frac{1}{10.00 \text{ mL}}$
 $= 0.263 \frac{\text{mol}}{\text{L}} \text{ CH}_3\text{COOH}$ The concentration of vinegar is 0.263 mol/L.

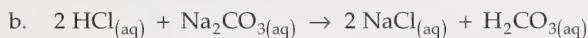
10. a. **Textbook question 1:**

$$n_{(\text{Na}_2\text{CO}_3)} = 0.100 \text{ L} \times \frac{0.100 \text{ mol}}{1 \text{ L}}$$

$$= 0.0100 \text{ mol}$$

$$m_{(\text{Na}_2\text{CO}_3)} = 0.0100 \text{ mol} \times \frac{105.99 \text{ g}}{1 \text{ mol}}$$

$$= 1.06 \text{ g}$$
 The mass of Na_2CO_3 required is 1.06 g.



11. Your data table will be similar to the following:

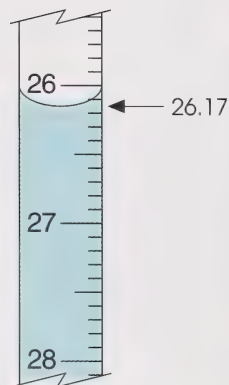
SAMPLE DATA

Titration of 10.0 mL Sample of 0.100 mol/L $\text{Na}_2\text{CO}_{3(\text{aq})}$ with $\text{HCl}_{(\text{aq})}$				
Trial	1	2	3	4
Final buret reading (mL)	20.01	20.18	22.64	20.12
Initial buret reading (mL)	0.11	0.12	2.61	0.15
Volume of HCl used (mL)	19.90	20.06	20.03	19.97
Average volume (mL) =	19.99			

Note: The average volume of $\text{HCl}_{(\text{aq})}$ used should be about 20.00 mL. The calculations which follow have used 20.00 mL as the average volume of $\text{HCl}_{(\text{aq})}$ used. Your average volume may be different but your calculated $\text{HCl}_{(\text{aq})}$ concentration should be close to (within 10%) the answers given here.

You will also notice that the volume measurements given here have two decimal places. Your buret may be such that you can estimate the second decimal place.

For example, the volume in the buret section to the right could be recorded as 26.17 mL. The 7 is considered significant because it is the first estimated digit – the other digits are certain, so all four digits are significant.



$$12. \quad a. \quad n_{(\text{Na}_2\text{CO}_3)} = \frac{0.100 \text{ mol Na}_2\text{CO}_3}{\cancel{\text{L}}} \times 0.0100 \cancel{\text{L}} \\ = 0.001 \text{ 00 mol Na}_2\text{CO}_3 \quad \text{The amount of Na}_2\text{CO}_3 \text{ that reacted is 0.001 00 mol.}$$

$$b. \quad n_{(\text{HCl})} = 0.001 \text{ 00 } \cancel{\text{mol Na}_2\text{CO}_3} \times \frac{2 \text{ mol HCl}}{1 \cancel{\text{mol Na}_2\text{CO}_3}} \\ = 0.002 \text{ 00 mol HCl} \quad \text{The amount of HCl that reacted is 0.002 00 mol.}$$

$$c. \quad C_{(\text{HCl})} = 0.002 \text{ 00 mol HCl} \times \frac{1}{0.020 \text{ L}} \\ = 0.10 \frac{\text{mol}}{\text{L}} \text{ HCl}$$

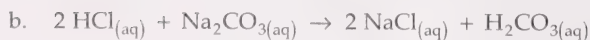
or

$$C_{(\text{HCl})} = 0.0100 \cancel{\text{L}} \times \frac{0.100 \cancel{\text{mol Na}_2\text{CO}_3}}{\cancel{\text{L}}} \times \frac{2 \text{ mol HCl}}{1 \cancel{\text{mol Na}_2\text{CO}_3}} \times \frac{1}{0.020 \text{ L}} \\ = 0.10 \frac{\text{mol}}{\text{L}} \text{ HCl} \quad \text{The concentration of the HCl}_{(\text{aq})} \text{ is 0.10 mol/L.}$$

13. a. Step 1:

$$n_{(\text{Na}_2\text{CO}_3)} = 0.100 \cancel{\text{L}} \times \frac{0.100 \text{ mol}}{\cancel{\text{L}}} \\ = 0.0100 \text{ mol}$$

$$m_{(\text{Na}_2\text{CO}_3)} = 0.0100 \cancel{\text{mol}} \times \frac{105.99 \text{ g}}{\cancel{\text{mol}}} \\ = 1.06 \text{ g} \quad \text{The mass of Na}_2\text{CO}_3 \text{ required is 1.06 g.}$$



14. Your data table may be similar to the following:

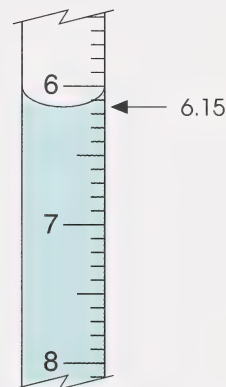
SAMPLE DATA

Titration of 10.0 mL Sample of 0.100 mol/L $\text{Na}_2\text{CO}_{3(\text{aq})}$ with $\text{HCl}_{(\text{aq})}$				
Trial	1	2	3	4
Final pipet reading (mL)	10.00 + 5.69	10.00 + 5.59	10.00 + 5.69	10.00 + 5.64
Initial pipet reading (mL)	0.02 + 0.04	0.03 + 0.00	0.06 + 0.02	0.01 + 0.03
Volume of HCl used (mL)	15.63	15.56	15.61	15.60
Average volume (mL) =	15.60			

The average volume of $\text{HCl}_{(\text{aq})}$ used should be about 15.60 mL. The calculations which follow have used 15.60 mL as the average volume of $\text{HCl}_{(\text{aq})}$ used. Your average volume may be different but your calculated $\text{HCl}_{(\text{aq})}$ concentration should be close to (within 10%) the answers given here.

You will also notice that the volume measurements given here have two decimal places. Your pipet may be such that you can estimate the second decimal place.

For example, the volume in the pipet section to the right could be recorded as 6.15 mL. The 5 is considered significant because it is the first estimated digit – the other digits are certain, so all three digits are significant.



$$15. \quad a. \quad n_{(\text{Na}_2\text{CO}_3)} = \frac{0.100 \text{ mol Na}_2\text{CO}_3}{\cancel{\text{L}}} \times 0.0100 \cancel{\text{L}} \\ = 0.00100 \text{ mol Na}_2\text{CO}_3 \quad \text{The amount of Na}_2\text{CO}_3 \text{ that reacted is } 0.00100 \text{ mol.}$$

$$b. \quad n_{(\text{HCl})} = 0.00100 \cancel{\text{mol Na}_2\text{CO}_3} \times \frac{2 \text{ mol HCl}}{1 \cancel{\text{mol Na}_2\text{CO}_3}} \\ = 0.00200 \text{ mol HCl} \quad \text{The amount of HCl that reacted is } 0.00200 \text{ mol.}$$

$$c. \quad C_{(\text{HCl})} = 0.00200 \text{ mol HCl} \times \frac{1}{0.01560 \text{ L}} \\ = 0.128 \frac{\text{mol}}{\text{L}} \text{ HCl}$$

or

$$C_{(\text{HCl})} = 0.0100 \cancel{\text{L}} \times \frac{0.100 \cancel{\text{mol Na}_2\text{CO}_3}}{\cancel{\text{L}}} \times \frac{2 \text{ mol HCl}}{1 \cancel{\text{mol Na}_2\text{CO}_3}} \times \frac{1}{0.01560 \text{ L}} \\ = 0.128 \frac{\text{mol}}{\text{L}} \text{ HCl} \quad \text{The concentration of the HCl}_{(\text{aq})} \text{ is } 0.128 \text{ mol/L.}$$

Section 2: Follow-up Activities

Extra Help

1.
 - a. iii
 - b. iv
 - c. ii
 - d. i
2.
 - a. **Titration** is an analytical procedure used to determine the concentration of a solution using a standard solution.
 - b. A solution of known concentration is called the **standard solution**.
 - c. The **titrant** is the solution in the buret.
 - d. The sudden change in a property of a solution indicating completion of a reaction is called the **end point**.
 - e. An **indicator** is a chemical added to a solution being titrated to signal the endpoint.
3.
 - a. The equipment required is as follows:
 - buret
 - buret clamp
 - funnel
 - retort stand
 - Erlenmeyer flask
 - pipet with bulb
 - b. Sodium hydroxide is the titrant.
 - c. Sodium hydroxide is the standard solution.

Enrichment

1. One method of determining the relative effectiveness of the antacid tablets is given here.

Materials/Reagents

- various antacid tablets, crushed
- bromothymol blue indicator
- 0.10 mol/L $\text{HCl}_{(\text{aq})}$
- 0.10 mol/L $\text{NaOH}_{(\text{aq})}$
- buret
- clamp
- 100 mL graduated cylinder
- retort stand

Procedure

- Fill a clean buret with the standard sodium hydroxide solution.
- Measure the mass of a clean Erlenmeyer flask.
- Transfer the crushed tablet to the flask and measure the mass to the nearest 0.01 g.
- Measure 100.0 mL of 0.10 mol/L $\text{HCl}_{(\text{aq})}$ in a graduated cylinder and add it to the flask. Dissolve as much tablet as possible (the fillers in the tablet may not dissolve completely).

- Add 1-3 drops of bromothymol blue to the sample. The indicator should be yellow. If the solution is blue, it means not enough $\text{HCl}_{(\text{aq})}$ was added. Add $\text{HCl}_{(\text{aq})}$ 10 mL at a time to the sample until you get a yellow-coloured solution.
- Record the initial buret reading.
- Titrate the sample in the flask with $\text{NaOH}_{(\text{aq})}$ until the solution changes to light blue. The $\text{NaOH}_{(\text{aq})}$ is neutralizing the excess $\text{HCl}_{(\text{aq})}$.
- Record the final reading of the buret.
- Repeat all the steps twice with the same brand of tablet and then repeat the procedure with any other brand for comparison. This procedure is called a *back titration*.

Evidence

mass of the Erlenmeyer flask and
the crushed antacid tablet = _____ g

– mass of the Erlenmeyer flask = _____ g

mass of antacid tablet = _____ g

Make a table similar to the following for each brand name you are using in your investigation.

BRAND NAME:

Titration of 0.10 mol/L $\text{HCl}_{(\text{aq})}$ with 0.10 mol/L $\text{NaOH}_{(\text{aq})}$			
Trial	1	2	3
Volume of $\text{HCl}_{(\text{aq})}$ (mL)			
Final buret reading (mL)			
Initial buret reading (mL)			
Volume of $\text{NaOH}_{(\text{aq})}$ used (mL)			
Average volume of $\text{NaOH}_{(\text{aq})}$ used =			

Analysis

Complete calculations such as the following for all brands and write a paragraph to summarize the relative effectiveness of these brands.

Calculations for (Brand name)

a. volume of $\text{HCl}_{(\text{aq})}$ used $\times$ concentration of $\text{HCl}_{(\text{aq})}$ = _____ mol of $\text{HCl}_{(\text{aq})}$

b. $\text{volume of NaOH}_{(\text{aq})} \times \text{concentration of NaOH}_{(\text{aq})} = \text{_____ mol of NaOH}_{(\text{aq})}$

Since the mole ratio of NaOH to HCl is 1:1, the moles of $\text{NaOH}_{(\text{aq})}$ used equals the excess moles of $\text{HCl}_{(\text{aq})}$.

c. $\text{mol of HCl}_{(\text{aq})} - \text{mol of NaOH}_{(\text{aq})} = \text{moles of HCl}_{(\text{aq})} \text{ neutralized by the tablet}$

d.
$$\frac{\text{moles of HCl}_{(\text{aq})} \text{ neutralized by tablet}}{\text{concentration of HCl}_{(\text{aq})}} = \text{volume of HCl}_{(\text{aq})} \text{ used by the antacid}$$

2. You will need to talk to laboratory technicians from different fields in industry. Some of the technicians may be from the following laboratories:

- medical
- water treatment plant
- petroleum industry
- environmental pollution control
- pharmaceutical

You can either visit the laboratories or get the information you need by phone. After you collect the information, analyse it and present your analysis, summarizing your views based on the information you gathered.

3. An investigation for finding the citrus juice with the highest acidity may be outlined as follows:

Materials/Reagents

- glass jars (such as baby food jars)
- eye dropper
- clear ammonia (household ammonia)
- fresh, frozen, or canned juice of the various citrus fruits (remove pulp by straining)
- phenolphthalein indicator (available at some drug stores)

Procedure

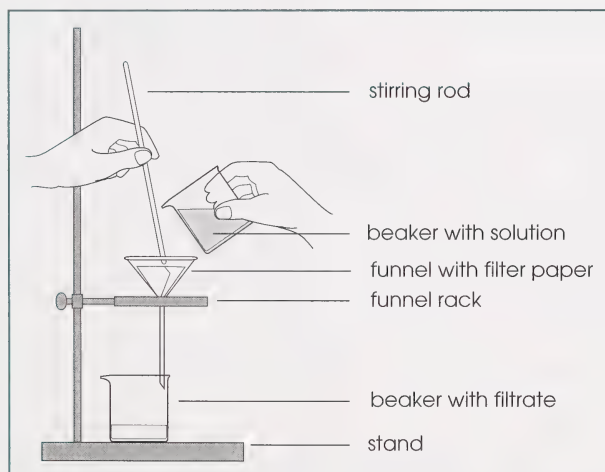
- Add a known volume of juice to a clean jar.
- Add 1-3 drops of phenolphthalein indicator.
- Add the ammonia solution by drops to the juice until a faint pink colour appears (this indicates the endpoint). Be careful with the ammonia. It is volatile and corrosive.
- Record the number of drops of ammonia used.
- Repeat the procedure three times for each juice.

Analysis

The juice that uses the maximum number of drops of ammonia has the highest acidity. Make a chart or graph showing the juices in order from highest to lowest acidity.

Section 3: Activity 1

1. You would choose a titration procedure.
2. The correct sequence of the steps is as follows:
 - d Heat the solid with a hot plate to drive off any remaining solvent, allow it to cool, and measure the mass of the solid.
 - a Record the mass of a clean, heat-resistant evaporating dish.
 - e Measure and record the mass of the dish and solid when dry.
 - b Pour a measured volume of solution in the evaporating dish.
 - c Evaporate the solution slowly either using a gentle heat source or letting it stand until all solvent evaporates.
3. The temperature of the solution can be increased to evaporate the solvent or the temperature of the solution can be decreased. The first method is used for quantitative analysis and the second is commonly used to purify or separate a solid.
4. The setup for filtration is as follows:

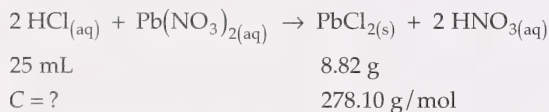


5. Factors important for obtaining accurate results in a filtration process include the following:
 - The liquid should not fill more than two-thirds of the filter paper at a time.
 - The precipitate collected should be washed at least twice to make sure no filtrate remains in the precipitate.
 - Rinse the stirring rod and the beaker containing the solution into the filter paper to make sure all the precipitate goes into solution.

Section 3: Activity 2

1. a. iii c. ii
 b. iv d. i
2. Chemical analysis techniques include the following:
 - gravimetric
 - optical analysis
 - volumetric
 - electrical analysis
3. a. The equipment and materials required include the following items:

• solution of kettle scale remover ($\text{HCl}_{(\text{aq})}$) • 1.05 mol/L lead(II) nitrate • distilled water bottle • filter paper • funnel • funnel stand • $\text{KI}_{(\text{aq})}$	• 250 mL beakers • stirring rod • watch glass • balance • dropper • graduated cylinder
---	---
- b. The analysis can be shown as follows:



$$n_{(\text{PbCl}_2)} = 8.82 \text{ g PbCl}_2 \times \frac{1 \text{ mol PbCl}_2}{278.10 \text{ g PbCl}_2}$$

$$= 0.0317 \text{ mol PbCl}_2$$

$$n_{(\text{HCl})} = 0.0317 \text{ mol PbCl}_2 \times \frac{2 \text{ mol HCl}}{1 \text{ mol PbCl}_2}$$

$$= 0.0634 \text{ mol HCl}$$

$$C_{(\text{HCl})} = \frac{0.0634 \text{ mol HCl}}{1} \times \frac{1}{0.025 \text{ L HCl}}$$

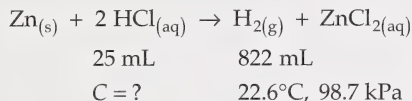
$$= 2.5 \text{ mol/L}$$

The molar concentration of the kettle scale remover acid ($\text{HCl}_{(\text{aq})}$) is 2.5 mol/L.

4. a. The materials and equipment required are as follows:

- kettle scale remover ($\text{HCl}_{(\text{aq})}$)
- zinc metal
- large plastic tray
- thermometer
- barometer
- 18×150 mm test tube
- 1-hole rubber stopper with glass tube
- rubber tubing
- 1000 mL graduated cylinder

b. The analysis can be shown as follows:



$$\begin{aligned} n_{(\text{H}_2)} &= \frac{pv}{RT} \\ &= \frac{98.7 \text{ kPa} \times 822 \text{ mL}}{\frac{8.31 \text{ kPa} \cdot \text{L}}{\text{mol} \cdot \text{K}} \times 295.6 \text{ K}} \\ &= 33.0 \text{ mmol} \end{aligned}$$

$$\begin{aligned} n_{(\text{HCl})} &= \frac{33.0 \text{ mmol H}_2}{1} \times \frac{2 \text{ mol HCl}}{1 \text{ mol H}_2} \\ &= 66.1 \text{ mmol HCl} \end{aligned}$$

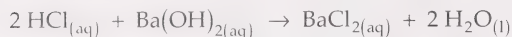
$$\begin{aligned} C_{(\text{HCl})} &= \frac{66.1 \text{ mmol HCl}}{1} \times \frac{1}{25 \text{ mL HCl}} \\ &= 2.6 \text{ mol/L} \end{aligned}$$

The molar concentration of the scale remover acid ($\text{HCl}_{(\text{aq})}$) is 2.6 mol/L.

5. a. The materials and equipment required are as follows:

- kettle scale remover ($\text{HCl}_{(\text{aq})}$)
- $\text{Ba}(\text{OH})_{2(\text{aq})}$
- distilled water bottle
- 250 mL waste beaker
- 100 mL beaker
- bromothymol blue indicator
- (2) 250 mL Erlenmeyer flasks
- funnel
- buret
- buret clamp
- ring stand
- 10 mL pipet with bulb

b. The analysis may be shown as follows:



10.0 mL 13.7 mL (avg.)

$C = ?$ 0.974 mol/L

$$n_{(\text{Ba}(\text{OH})_2)} = \frac{13.7 \text{ mL Ba}(\text{OH})_2}{1} \times \frac{0.974 \text{ mol Ba}(\text{OH})_2}{1 \text{ L Ba}(\text{OH})_2}$$

$$= 13.3 \text{ mmol Ba}(\text{OH})_2$$

$$n_{(\text{HCl})} = 13.3 \text{ mmol Ba}(\text{OH})_2 \times \frac{2 \text{ mol HCl}}{1 \text{ mol Ba}(\text{OH})_2}$$

$$= 26.7 \text{ mmol HCl}$$

$$C_{(\text{HCl})} = 26.7 \text{ mmol HCl} \times \frac{1}{10.00 \text{ mL HCl}}$$

$$= 2.67 \text{ mol/L}$$

The molar concentration of the scale remover acid ($\text{HCl}_{(\text{aq})}$) is 2.67 mol/L.

6. Textbook question 44:

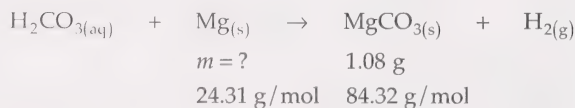
a. The titration (Lab Exercise 7K) is the best design for the following reasons:

- It had more than one trial.
- It is efficient.
- It gave a more precise answer (more decimal places).

b. An alternate design using zinc and hydrochloric acid would be to measure the following:

- mass of zinc before reaction (g)
- mass of zinc after reaction (g)
- mass of zinc used during the reaction (g)

7. Design A analysis



$$n_{(\text{MgCO}_3)} = 1.08 \text{ g MgCO}_3 \times \frac{1 \text{ mol MgCO}_3}{84.32 \text{ g MgCO}_3}$$

$$= 0.0128 \text{ mol MgCO}_3$$

$$n_{(\text{Mg})} = 0.0128 \text{ mol MgCO}_3 \times \frac{1 \text{ mol Mg}}{1 \text{ mol MgCO}_3}$$

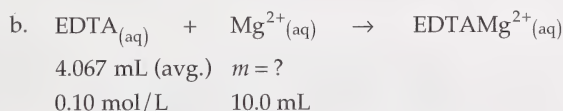
$$= 0.0128 \text{ mol Mg}$$

$$m_{(\text{Mg})} = 0.0128 \cancel{\text{mol Mg}} \times \frac{24.31 \text{ g}}{1 \cancel{\text{mol Mg}}} \\ = 0.311 \text{ g}$$

The mass of Mg is 0.311 g.

8. Design B analysis

$$\begin{aligned} \text{a. average volume of EDTA used} &= \frac{4.0 \text{ mL} + 4.1 \text{ mL} + 4.1 \text{ mL}}{3} \\ &= 4.067 \text{ mL} \\ &= 4.1 \text{ mL} \end{aligned}$$



$$\begin{aligned} n_{(\text{EDTA})} &= \frac{0.10 \text{ mol EDTA}}{1 \cancel{\text{L}}} \times 0.04067 \cancel{\text{L}} \\ &= 0.004067 \text{ mol EDTA} \end{aligned}$$

$$\begin{aligned} n_{(\text{Mg}^{2+})} &= 0.004067 \cancel{\text{mol EDTA}} \times \frac{1 \text{ mol Mg}^{2+}}{1 \cancel{\text{mol EDTA}}} \\ &= 0.004067 \text{ mol Mg}^{2+} \\ &= 0.004067 \text{ mol Mg} \text{ (The difference in mass between Mg}^{2+} \text{ and Mg is negligible.)} \end{aligned}$$

$$\begin{aligned} m_{(\text{Mg}^{2+})} &= 0.004067 \cancel{\text{mol Mg}} \times \frac{24.31 \text{ g}}{1 \cancel{\text{mol Mg}}} \\ &= 0.09887 \text{ g} \\ &= 0.10 \text{ g} \end{aligned}$$

The mass of magnesium in a 10 mL sample is 0.10 g.

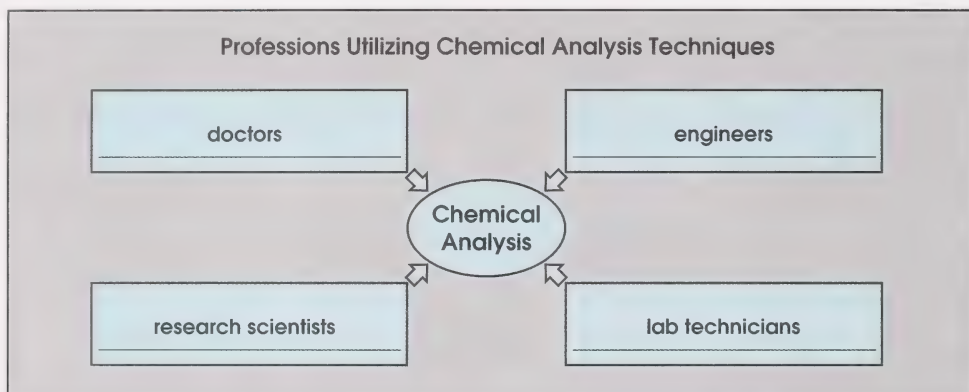
9. Design B is better for the following reasons:

- More than one trial is included.
- It is more efficient.
- It gives a more accurate answer.
- In Design A a major source of error is that other metallic impurities such as aluminum or titanium will also react with the acid to produce precipitates. Therefore the mass of the precipitate collected will represent masses of the metallic impurities as well.

10. If gas plants did not use scrubbing towers to remove gases such as $\text{H}_2\text{S}_{(\text{g})}$, there would be several consequences.
- The increased $\text{H}_2\text{S}_{(\text{g})}$ concentration in the atmosphere would contribute to an increased concentration of acid rain.
 - The $\text{H}_2\text{S}_{(\text{g})}$ would also contribute to the corrosion of metal and painted surfaces on buildings, playgrounds, etc.
 - There would be an increased health risk to plants and animals.

Section 3: Activity 3

1. Answers may vary. Possible responses include the following:



2. a. The term *forensic* usually relates to legal proceedings. The term *forensic* means belonging to or used in courts or public discussion.
- b. Carolyn relies on the following types of technology:
- microscopy
 - infrared spectroscopy
 - gas chromatography
 - X-ray diffraction
- c. Carolyn performs the following duties:
- analyses various materials related to crimes
 - prepares reports for investigators
 - appears as an expert witness in court
- d. Carolyn's educational background includes a high school diploma and a B.Sc. degree in chemistry.
- e. Carolyn recommends taking courses in chemistry, physics, mathematics, and computer studies (option). Doing well in these courses would provide a range of options for students wishing a career in a science-related field.

3. The occupations of the people profiled in the video are as follows:

- Dr. E. Prepas – professor of limnology
- Mark Serediak – research technician
- Jay Babin – research assistant
- Debbie Webb – graduate student/instructor

4. The people interviewed all suggest that a good high school background in mathematics and science will allow the student more options later.

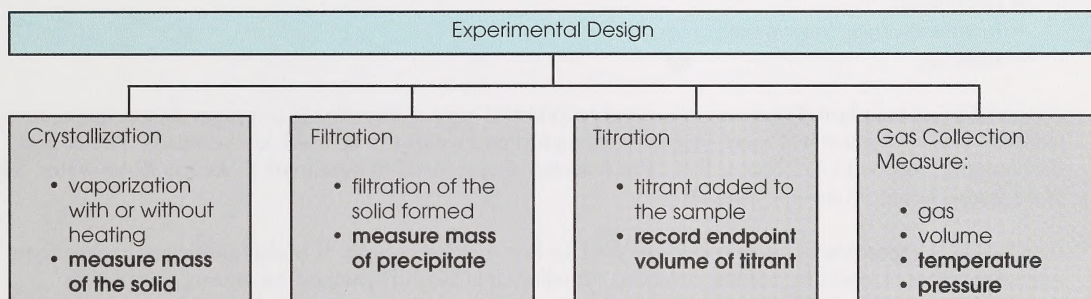
5. You should approach your career choice in the following ways:

- Talk to people in fields you are interested in. They can give you firsthand advice on the background you need.
- Be flexible in your background; mechanical skills as well as science and math skills are valuable.

Section 3: Follow-up Activities

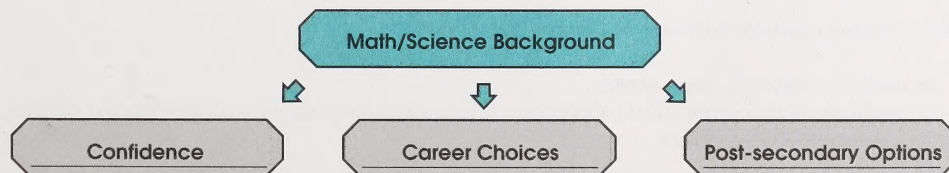
Extra Help

1.



2. a. Only one **variable** should be manipulated at a time.
- b. The **cost** of performing the experiment should be as **low** as possible.
- c. The **responding** variable should be observed consistently.
- d. The design should include a **control group**.
- e. The design should have little adverse effect on the **environment**.

3.



Enrichment

1. A modified titration procedure is used to determine the chlorine concentration in the water. The design is time-efficient, gives a precise answer, is simple to use, and is reliable.

A buffer solution is added to a sample of water to get the desired pH. Potassium iodide is also added. The titrant used is phenylarsine oxide.

The endpoint is not indicated by a colour change. Instead, the conductivity of the reaction mixture is constantly tested with a probe. When the conductivity does not change, the endpoint is reached.

2. Fresh water resources in many parts of the world cannot meet the demand for water, either for daily needs or for agriculture. Pure water is also needed for certain industries such as electronics and liquor manufacturing. High pressure boilers, used in industrial plants, need completely demineralized water.

To meet these needs desalinizing plants have been designed. The plants take seawater (with 35 000 ppm dissolved salt) and remove the minerals from it so that the water can be used. There are three methods used to desalinize water:

- distillation
- reverse osmosis (uses membranes)
- freezing

The location of the plant determines the most economical type of plant for that region. In Manitoba, reverse osmosis is used because it is more cost-efficient and inland water can be used as a resource. The largest desalinizing plant is in Arizona, U.S.A. The Arizona plant is used to desalinate Colorado River water. This plant is also based on reverse osmosis.

Distillation is expensive because the cost of fuel for this method is high. It is also inefficient to desalinate large quantities of water by reverse osmosis. However it is the only method for getting completely demineralized water. Freezing water is most economical in regions with cold climates because water is already at a lower temperature. Energy does not have to be spent on cooling the water.

3. Catalytic incinerators are used in burning the waste-product fumes collected in refineries. They lower the heat required for the combustion of waste fumes, making it a more efficient process. The heat produced during the burning is recycled to preheat the waste products.

Advantages of using catalytic incinerators include the following:

- They lower operating costs in the form of fuel savings.
- They offer a balance between capital cost and operating cost.

Disadvantages of using catalytic incinerators include the following:

- They are used for relatively clean waste.
- They are inefficient when some substances poison the catalyst by reacting with the catalyst surface.
- Catalysts are extremely expensive.

